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AIRCRAFT CABIN FIRE FIGHTING TRAINING SIMULATOR SPECIFICATIONS

Prepared for

TRANSPORTATION DEVELOPMENT CENTRE
POLICY AND COORDINATION GROUP
TRANSPORT CANADA

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16. Abstract

The specifications of an advanced fire fighting training simulator were developed. The scope of the study was limited to "on board fires" only, exclusive of post crash fires. The study began with selected interviews of industry and government officials in Canada, USA and Europe. The interviewees were involved in research and implementation of the relevant training practices for aircrew and flight attendants. An extensive literature search was conducted as well as a review of videos of live fire tests conducted by the FAA in Atlantic City. The potential locations on board the aircraft and the types of fires were examined with a view to simulation of the phenomenon. A number of technologies and pedagogic considerations were identified and presented, in addition to the final specifications of the advanced simulator.

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16. Résumé

Cette étude entreprise en vue de définir les critères de conception d'un simulateur d'incendie amélioré a porté uniquement sur les feux susceptibles de se produire en vol, à l'exclusion des incendies provoqués par un écrasement au sol. Des consultations ont d'abord eu lieu auprès de représentants de l'industrie et des gouvernements du Canada, des États-Unis et de pays d'Europe qui jouent un rôle dans la recherche et dans l'élaboration des programmes de formation du personnel navigant. Les chercheurs ont fait une recherche documentaire poussée et ont visionné des enregistrements vidéo d'exercices de lutte contre des feux réels menés par la FAA à Atlantic City. Les classes de feux possibles ainsi que les endroits dans la cabine où ils risquent de se déclarer ont été considérés en vue de la simulation. Diverses considérations techniques et pédagogiques sont présentées avec les critères à retenir pour la conception du simulateur envisagé.

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SUMMARY

This document reports on a study to identify, describe and evaluate technologies and techniques with which an aircraft cabin fire training simulator could be devised.

The methodological steps undertaken involved :

a) The determination of the historical or potential aircraft cabin fires exclusive of post crash fires.

b) An investigation of the characteristics of the fires in terms of the stimulus to the human faculties, and the initiation and growth characteristics of the relevant phenomena such as smoke, flame, heat, smell, noise, and deformation of materials.

c) Investigation of the techniques and devices for neutralising and/or extinguishing the fires.

d) Investigation of the available techniques and technologies for providing the simulated cues for the detection of the existence of fires. This included issues of instructor workload and the effectiveness of the training in terms of feedback, variations in scenarios and other pedagogic items.

e) Investigation of the technologies and techniques for simulating the neutralising and or extinguishing action on the simulated fires.

f) Investigation of current and potential devices which could replicate (simulate) the "feel" and "operation" of the real devices.

g) Investigation of the potential for an integrated device incorporating the technologies and devices identified during this study.

The types of fires to be simulated were defined in terms of their locations, which were the galley area, overhead bins, lavatory areas, cargo containers (Class B), passenger seats, other passive areas such as neon lights and projectors.

The elements to be simulated were smoke, flame, smell, noise, heat and material deformation. Toxicity and nausea, while potentially reproducible in a simulator, were excluded from the study.

It was found that the current industry training was limited to the operation of fire extinguishers, manoeuvring and communication in smoke filled environments, and the use of Protective Breathing Equipment (PBE).

The training equipment consisted of actual fire extinguishers (halon and water), real fires which were lit in a controlled environment (fire pit or some piece of aircraft interior in an open outdoor area), compressed air fire extinguishers where some types of smoke and flame were simulated, smoke generators with constant colour smoke, and lights to simulate flames.

The problems of current training, identified by industry personnel, were that halon left residue and caused pollution, realism of aircraft cabin was absent, communication was difficult with PBE, frequency of hands-on training was inadequate, and cost of unit training was high.

The consultants determined additionally that smoke colour and intensity were incorrectly simulated, extinguishment of the fire was not detected correctly, the range of training scenarios was very limited, evaluation of the performance was difficult and

mostly subjective, progressive fire fighting was not possible, and many of the cues for signalling fires were not used in training.

The results of the literature search were summarised in a matrix, which showed the fire types and the characteristics which have been researched previously. The empty cells of the matrix were addressed by the consultants on the basis of their judgement and expertise. The fire sources and the equipment to be used in actual fires were also identified.

The relevant design considerations were the requirement for a completely computer controlled system with feedback control logic involving interaction between the computer, simulator, instructor and student. Further, the simulation of the history of the various cues, without and with intervention, was determined to be desirable.

The technology for various component simulations was identified as follows:

a) Fire (flame) using holography, projection onto smoke, vapour or black screen.

b) Sound, using recording or computer generated.

c) Smoke, using theatrical devices with a range of four colours (white, yellow, blue, and grey).

d) Temperature effects with heat generated from infra-red lamps or heating coils (buried).

e) Smell from odour generators of required duration.

f) Material deformation with mechanical or inflatable materials with elastic properties.

It was concluded that current technology is sufficiently advanced to produce a considerably improved fire fighting training simulator. The design specifications for a more advanced simulator should be accompanied by a more advanced approach to training, which could be made more comprehensive.

SOMMAIRE

La présente étude avait pour objet de repérer et d'évaluer les moyens technologiques susceptibles de servir à la mise au point d'un simulateur d'incendie en cabine d'aéronef.

Les chercheurs ont procédé à un examen systématique des divers éléments suivants :

a) cas d'incendies en cabine survenus dans le passé ou susceptibles de se produire, à l'exclusion des incendies provoqués par l'écrasement au sol de l'appareil;

b) phénomènes qui accompagnent ces divers types de feux et agissent sur les sens, c'est-à-dire flammes, fumée, chaleur, odeur, bruit, déformation des matériaux, et ce qui caractérise leur apparition et leur évolution;

c) techniques et moyens d'intervention permettant de maîtriser et d'éteindre le feu;

d) moyens technologiques existants qui permettraient de simuler les phénomènes qui signalent la présence d'un feu. À ce chapitre, la charge de travail des instructeurs, l'efficacité de la formation sous le rapport de l'interaction, la diversité des scénarios simulés et d'autres questions d'ordre pédagogique ont été considérés;

e) moyens technologiques qui permettraient de simuler l'effet de l'intervention sur la situation simulée;

f) moyens existants ou à mettre au point qui permettraient de reproduire la sensation qui accompagne la manipulation ou la manoeuvre des dispositifs réels;

g) faisabilité d'un modèle intégré réunissant toutes les techniques et tous les dispositifs jugés utiles.

Les types de feux à simuler ont été déterminés d'après les foyers possibles, c'est-à-dire office, compartiments de rangement supérieurs, toilettes, soutes (classe B), sièges de passagers, appareils d'éclairage au néon et projecteurs.

Les phénomènes à simuler seraient la fumée, les flammes, l'odeur du feu, le bruit, la chaleur et la déformation des matériaux. Bien qu'il soit possible de les reproduire, l'effet d'intoxication et la sensation de nausée ont été écartés.

L'étude a révélé que la formation que donne l'industrie se limitait à la manoeuvre des extincteurs, à la manière de remplir ses fonctions et de communiquer dans une atmosphère remplie de fumée et à l'utilisation d'appareils de protection respiratoires.

Le matériel de formation comprend de véritables extincteurs (à eau ou à produits halogénés) utilisés pour des exercices d'intervention contre un feu réel en conditions contrôlées (enceinte d'exercice ou partie de cabine d'aéronef placée dans un endroit dégagé), des extincteurs sous pression pour les exercices en conditions spéciales de flammes et de fumée, des générateurs de fumée produisant une fumée de couleur uniforme et des projecteurs pour simuler les flammes.

Les faiblesses des programmes actuels de formation soulevées par l'industrie et le personnel auquel cette formation s'adresse sont le caractère polluant des produits halogénés, le manque de réalisme des simulations, la difficulté de communiquer avec un appareil de protection respiratoire, la fréquence insuffisante des exercices pratiques et le coût élevé de la formation.

Les chercheurs ajoutent que la couleur et la densité de la fumée ne sont pas correctement simulées, les effets des interventions ne sont pas bien relevés, la diversité des scénarios simulés est très limitée, l'évaluation de l'efficacité de l'intervention est difficile et très subjective, la simulation de l'évolution du feu en rapport avec l'intervention est impossible et plusieurs des indices permettant de détecter la présence d'un feu ne sont pas utilisés.

Les résultats de la recherche documentaire ont été résumés sous forme de tableau indiquant les divers types de feux possibles et leurs caractéristiques. Les chercheurs ont ensuite rempli les cases demeurées vides d'après leurs connaissances et leur expérience en la matière. Ils ont également déterminé les foyers possibles et le matériel d'intervention à utiliser dans chaque cas.

L'étude a mené à la conclusion que le modèle de simulation d'incendies devait être entièrement commandé par ordinateur et devait comporter une logique de commande interactive reliant l'ordinateur, le simulateur, le poste de l'instructeur et celui du sujet. De plus, il serait souhaitable que l'évolution des divers phénomènes dont s'accompagne un feu soit aussi simulée, avec ou sans les effets de l'intervention.

Les moyens technologiques envisagés pour la simulation des divers caractères du feu sont les suivants :

a) flammes : holographie, avec projection sur un écran noir, un écran de fumée ou un écran de vapeur;

b) bruit : enregistrement magnétique ou synthèse par ordinateur;

c) fumée : matériel de théâtre, pouvant produire quatre couleurs de fumée (blanc, jaune, bleu et gris);

d) chaleur : lampes à infrarouges ou appareils de chauffage (enfouis);

e) odeur : générateurs d'odeurs de durée voulue;

f) déformation des matériaux : matériaux mécaniques ou gonflables et élastiques.

Les chercheurs sont arrivés à la conclusion que la technologie actuelle offre les moyens de créer un simulateur d'incendie considérablement plus avancé que ce dont l'industrie dispose. La conception d'un tel simulateur appelerait une révision de l'approche de la formation, qui pourrait être rendue plus complète.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AGARD	Advisory Group for Aerospace Research & Development
APS	Aviation Planning ServicesLtd.
ASTM	American Society For Testing and Materials
BSI	British Standards Institute
CAA	Civil Aviation Authority
FAA	Federal Aviation Administration
HCL	Hydrogen Chloride
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride
NFPA	National Fire Protection Association
NIST	National Institute of Science and Technology
PBE	Protective Breathing Equipment
TC	Transport Canada
TDC	Transportation Development Centre
TSO	Technical Standard Orders

1. INTRODUCTION

At the request of Transportation Development Centre (TDC) of Transport Canada (TC), Aviation Planning Services Ltd. (APS) undertook a study to identify, describe and evaluate technologies and techniques with which an advanced aircraft cabin fire training simulator could be devised.

The initial specifications of the fire fighting simulator were that it should permit training of aircraft cabin personnel in fire fighting without the presence of burning material, flames or combustion gases. Further, it should correctly simulate a number of fire situations in an aircraft passenger cabin. These included fires in the galley, toilet, passenger seats, hidden areas and in the luggage spaces normally accessible to passengers and/or crew in flight. The specifications did not include exterior fires or those following an operational incident. Therefore, these were not considered in this study.

In the original specifications, the fire situations to be simulated involved the production of smoke and heat, without visible flames. Examples of these situations included combustion within cabin linings and other spaces not directly accessible by cabin personnel. Subsequently, APS hypothesized that current technology may allow the inclusion also of flames and other attributes which characterize aircraft cabin fires. Therefore, the study began by expanding on the original specifications. The final product of the study was the identification of suitable technologies and resource requirements for possible follow-on projects involving demonstrations of the technologies and a prototype of the simulator.

This document describes the process undertaken by APS in the specification formulation, research methodology, data sources access, conceptual exercises and results generation, which lead to the fulfilment of the requirements of the study.

2. METHODOLOGY

The methodological steps proposed by APS involved the following:

i) Determination of the historical types of fires which occur or could occur in aircraft cabins and which could be fought by airborne cabin and/or flight crew.

ii) Investigation of the characteristics of the fires in terms of:

a) the stimulus to the human faculties of sense, smell, touch, vision and hearing;

b) initiation and growth characteristics of the relevant perceivable phenomena such as smoke, flame, heat, smell, noise, and deformation of materials.

iii) Investigation of the techniques and devices for neutralising and/or extinguishing the fires. This included the establishment of priorities among the set of stimuli referenced in item (ii a).

iv) Investigation of the available techniques and technologies for providing the simulated cues for the detection of the existence of fires as determined in item (ii). This included, to the extent possible, issues such as instructor workload and the effectiveness of the training in terms of feedback, variations in scenarios and other pedagogic issues.

v) Investigation of the technologies and techniques for simulating the neutralising and or extinguishing action on the simulated fires to provide a response of a diminution or cessation of the characteristics described in item (ii).

vi) Investigation of current and potential devices which could replicate (simulate) the "feel" and "operation" of the real devices identified in (iii).

vii) Investigation of the potential for an integrated physical simulator incorporating the technologies and devices identified during this study.

The work plan for the study initially relied extensively on telephone and personal interviews with air carriers, scientists, government regulatory agencies and cabin crew training organisations. After some interviews, an extensive literature search was conducted, including published journals and documents provided by the agencies interviewed. Preliminary results were summarized and reviewed with the appropriate government agencies. Following this, a conceptual design of the simulator specifications was developed and the required technologies established. From this, the specifications for the technology and demonstrations were determined.

During the course of the study, it was established that practical experience in real fire situations on board commercial aircraft would be a useful input. Therefore aircrew who have been involved with such situations were sought. However, the carriers contacted were unable to officially release any personnel for this study. Nevertheless, informal discussions with some flight personnel did provide data which was used in the study.

3. FORMULATION OF SPECIFICATIONS

This section describes the process by which the specifications were formulated by APS.

3.1 Interviews

The study involved a number of interviews and/or visits to TC Headquarters, Federal Aviation Administration (FAA) Technical Centre, Civil Aviation Authority (CAA), National Institute of Science and Technology (NIST), manufacturers of simulators and selected major air carriers in Canada, USA and Europe. The list of contacts has been included in this report as Appendix A.

3.2 Types of Cabin Fires

From the airlines and TC, the following list of the locations and types of fires encountered in flight was established :

i) Fires in galley area. These consisted of fires within the ovens (food), from behind the ovens (electrical), in the hot cup devices (electrical), behind the wall panels (electrical) and from the galley waste bins (paper or chemical).

ii) Overhead bin fires. These consisted of carry on baggage generated fires (paper, chemical, inflammable fuel) as well as electrical fires from behind the panelling.

iii) Lavatory area fires. These included waste bin (paper), behind wall panelling (electrical) and flush motor beneath the floor (electrical).

iv) Cargo container fires. These were of importance in this study due to the increasing use of "combi" aircraft, where passengers and cargo share the cabin. The nature of the fires could be paper, chemical (inflammable fuels) or electrical.

v) Passenger seating fires. These included the seat cushions, under seat and seat back areas. The materials of combustion could be the same as the overhead bin fires.

vi) Other passive area fires. These included overhead neon lighting fixture ballasts, projectors, audio equipment and general wiring behind all cabin panels. All of these would be classified as electrical fires.

3.3 Hypothesis

During initial conceptualisation and brainstorming exercises, jointly undertaken by TC and APS, it was conceptualized that the ideal fire fighting training forum should be one in which a member of the crew would be required to identify the location and source of the fire and then take appropriate corrective action. There would then be perceptual feedback to the fire fighter and performance identification to the instructor. This implied a training device which would foster a degree of diagnostic analysis, decision making and response quality as well as time. Therefore, the initial hypothesis formulated by APS was that there existed adequately advanced technology and techniques to devise such a simulator.

3.4 Elements to be Simulated

The fire fighting simulator should produce a variety of stimuli. These were broadly categorized according to the interaction with the human faculties and in a form convenient for a study of potential means of simulating the stimuli. Therefore, the following list was developed:

- smoke
- flame
- smell
- noise
- heat
- material deformation

The issue of hazardous and non-hazardous or toxic versus non toxic stimuli was also considered although the requirement for a safe training device precluded the simulation of toxicity or any nausea creating environments, although it is possible.

Given the above list, locations and types of fires, the next step was the study of the phenomena in the list and at the locations cited in section 3.2. This was conducted through literature search and interviews with industry representatives. Concurrent with this step, a review was conducted of the training practices among the carriers to determine to what extent and with what technology the training objectives were being met. This review is described in the next section while the scientific work has been deferred to later sections.

4. INDUSTRY TRAINING REVIEW

Five major airlines were contacted during this study. One Canadian, three US and one European carrier were visited and the appropriate training personnel interviewed. In addition, the Civil Aviation Authority (CAA) Fire Service Training School (UK), and the FAA full-scale fire test facility (US) were visited. This section describes the training objectives and the equipment/technology used.

4.1 Training objectives

The airlines and the CAA reported that their training currently consisted of some or all of the following elements:

i) Training to operate the fire extinguishers (water and halon) on a pre identified fire, either in a specially designed room with a fire pit, outdoors in a container such as an oven or a mock up of a lavatory waste bin, or, in one case, in various areas of a cabin mock-up constructed within a steel container.

Plate 4.1 shows a CAA cargo container within which a paper fire is lighted in a pot approximately 65 cm. in height and 33 cm diameter. The candidates are required to enter the container and extinguish the fire.

Plates 4.2, 4.3 and 4.4 show another cargo container, one side of which houses a lavatory mock up and another a galley mock up. Actual fires are lit in the these areas. The candidates are required to extinguish the fires by discharging extinguishing agents through appropriate openings to reach the fire sites.

PLATE 4.1

CLASS A FIRE FIGHTING TRAINING FACILITY
USE OF EXTINGUISHER

SOURCE: CAA FIRE SERVICE TRAINING SCHOOL, APS PHOTO

PLATE 4.2

CARGO CONTAINER
LAVATORY FIRE TRAINING MODULE

SOURCE: CAA FIRE SERVICE TRAINING SCHOOL, APS PHOTO

PLATE 4.3

INTERIOR OF LAVATORY FIRE TRAINING MODULE

SOURCE: CAA FIRE SERVICE TRAINING SCHOOL, APS PHOTO

PLATE 4.4

GALLEY FIRE TRAINING MODULE

SOURCE: CAA FIRE SERVICE TRAINING SCHOOL, APS PHOTO

ii) Training to manoeuvre in a smoke-filled environment and communicate with other flight attendants, captain, and passengers. Plate 4.5 shows an exterior view of the CAA aircraft cabin (Vickers Viscount), equipped for this type of exercise. Here, exposure to a dark and/or smoke-filled confined space is also a consideration.

In the airline facilities reviewed, the mock-ups also catered to evacuation or escape procedures (crawling on the floor) during smoke and fire fighting. Plates 4.6 and 4.7 show the Lufthansa mock-ups of a Boeing 747 and an Airbus A-320.

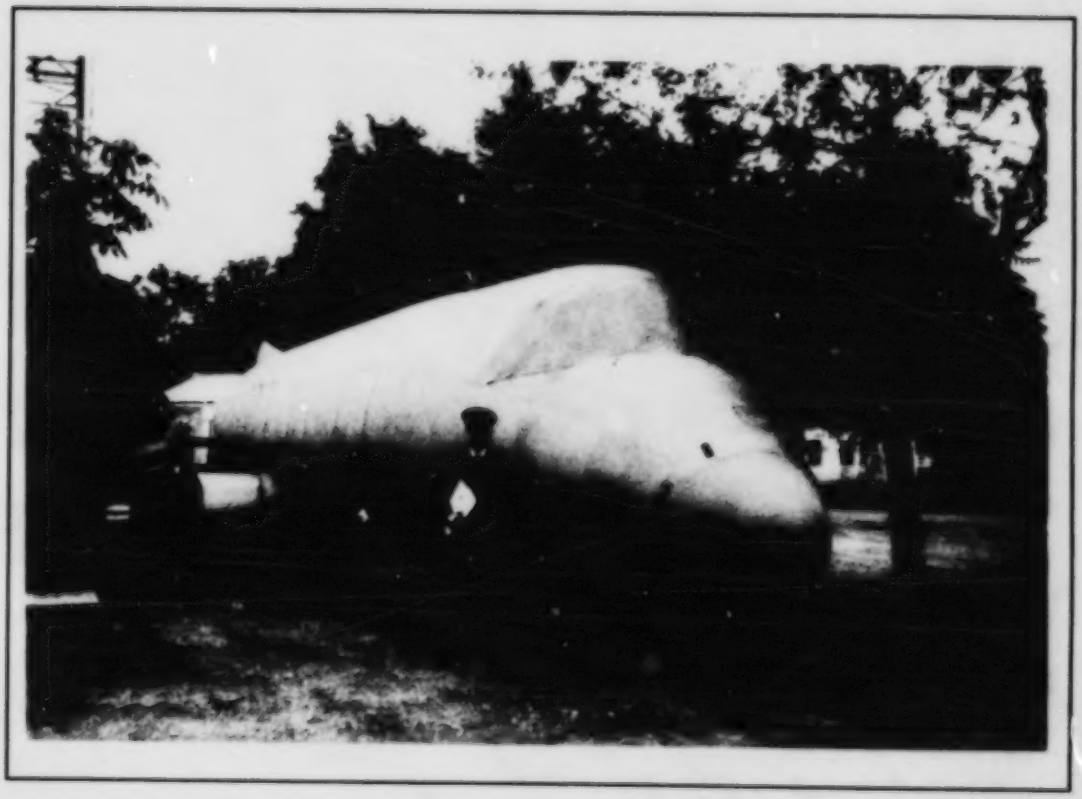
Other mock ups do exist, and they offer various cabin sizes and cross sections. All have, to a lesser or greater extent, some cabin seats, sections of outer cabin walls, lavatory and galley mock-ups. Plate 4.8 shows an example of a galley mock-up and a simulated bin fire being extinguished. Plate 4.9 shows a row of seats with a carry-on baggage fire.

Some carriers are currently operating "Combi" aircraft, where cargo pallets are loaded within the same pressurized cabin compartments as passengers. The techniques for fire fighting class B fires are therefore somewhat different from those for strictly cargo aircraft (class D fires). Plates 4.10 and 4.11 show different views of a cargo pallet where a simulated fire and smoke may be generated.

iii) Training in the use of the Protective Breathing Equipment (PBE) and exposure to the operational requirements while wearing the device. Plate 4.12 shows one type of PBE used by the CAA for training.

PLATE 4.5

COMPLETE CABIN SMOKE AND FIRE TRAINING MODULE



SOURCE: CAA FIRE SERVICE TRAINING SCHOOL, APS PHOTO

PLATE 4.6

LUFTHANSA BOEING 747 CABIN TRAINING MODULE

SOURCE: LUFTHANSA GERMAN AIRLINES, APS PHOTO

PLATE 4.7

LUFTHANSA A-320 CABIN TRAINING MOCK UP

SOURCE: LUFTHANSA GERMAN AIRLINES, APS PHOTO

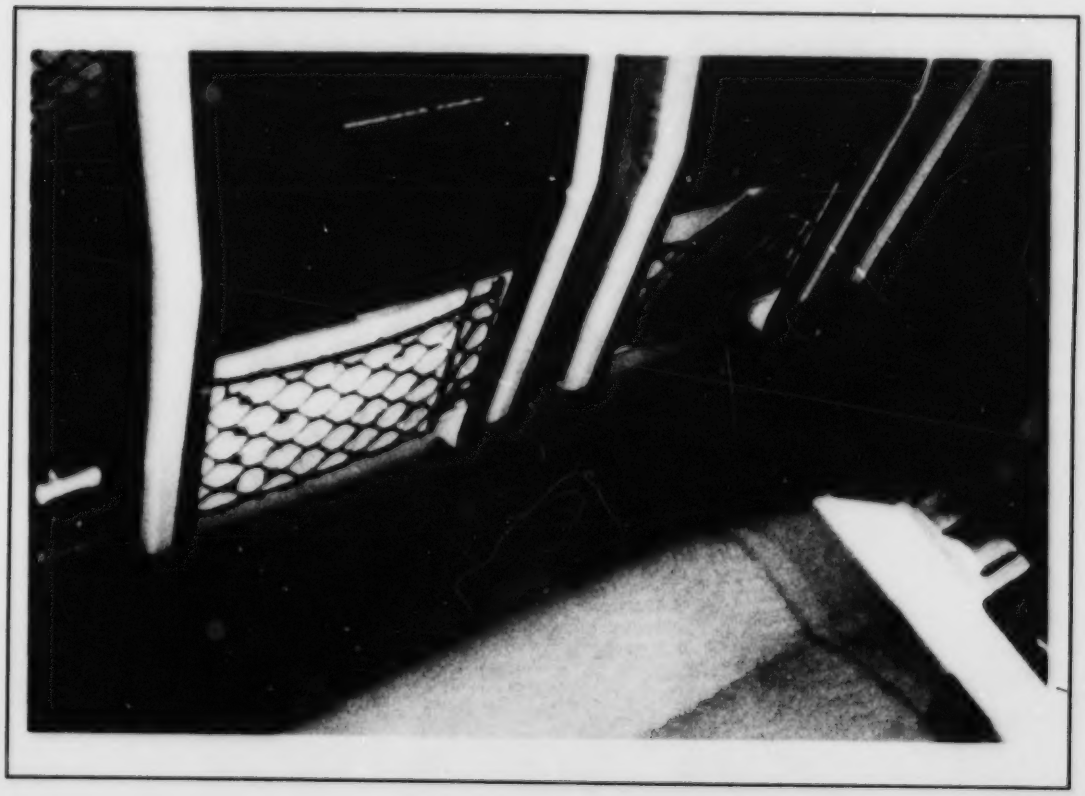
PLATE 4.8

LUFTHANSA A-320 GALLEY FIRE MODULE

SOURCE: LUFTHANSA GERMAN AIRLINES, APS PHOTO

PLATE 4.9

LUFTHANSA CARRY ON BAGGAGE/UNDER SEAT FIRE MODULE



SOURCE: LUFTHANSA GERMAN AIRLINES, APS PHOTO

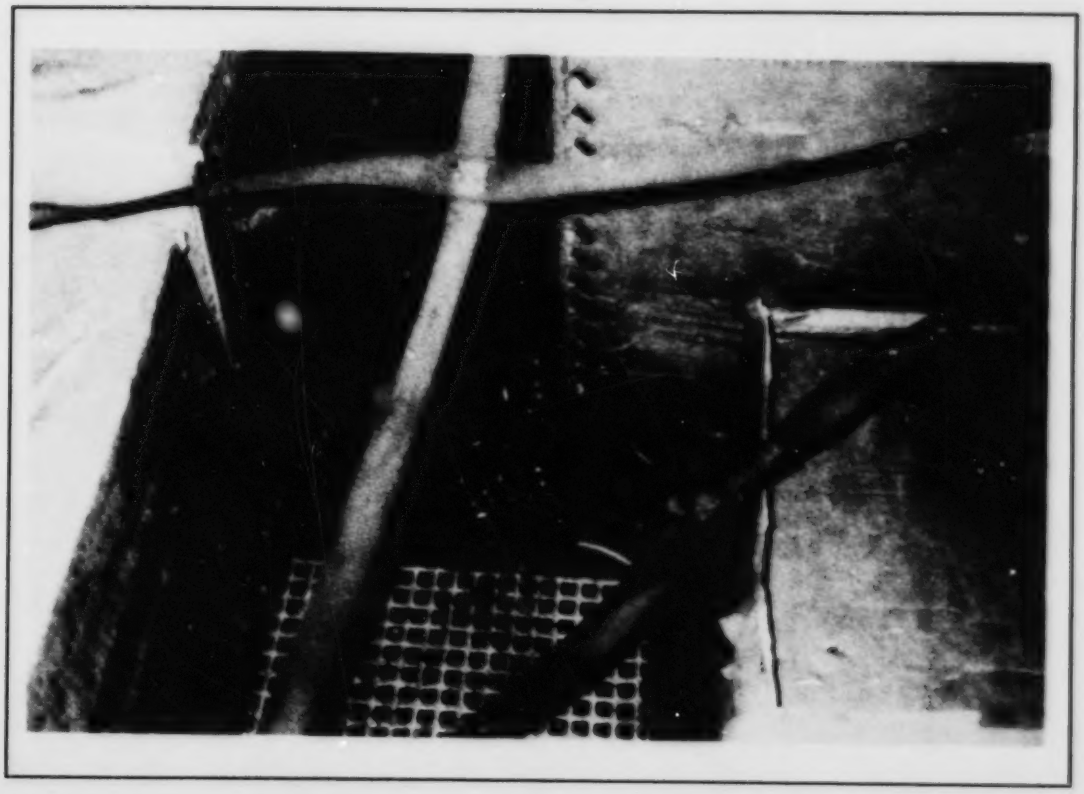
PLATE 4.10

CARGO PALLET FIRE TRAINING MODULE

SOURCE: LUFTHANSA GERMAN AIRLINES, APS PHOTO

PLATE 4.11

SIMULATOR CARGO PALLET FIRE



SOURCE: LUFTHANSA GERMAN AIRLINES, APS PHOTO

PLATE 4.12

PROTECTIVE BREATHING EQUIPMENT TRAINING DEVICE

SOURCE: CAA FIRE SERVICE TRAINING SCHOOL, APS PHOTO

4.2 Training Equipment

Actual fires are lighted with paper or small amounts of fuel in pots, pans, bins or partial seats. The standard fire extinguishers (Halon and water) are used for extinguishment. As a first defence against class A fires, the CAA also demonstrates the effectiveness of consumable liquids in extinguishing (cooling) fires by having the candidates pour water from a tea pot onto an ignited seat cushion.

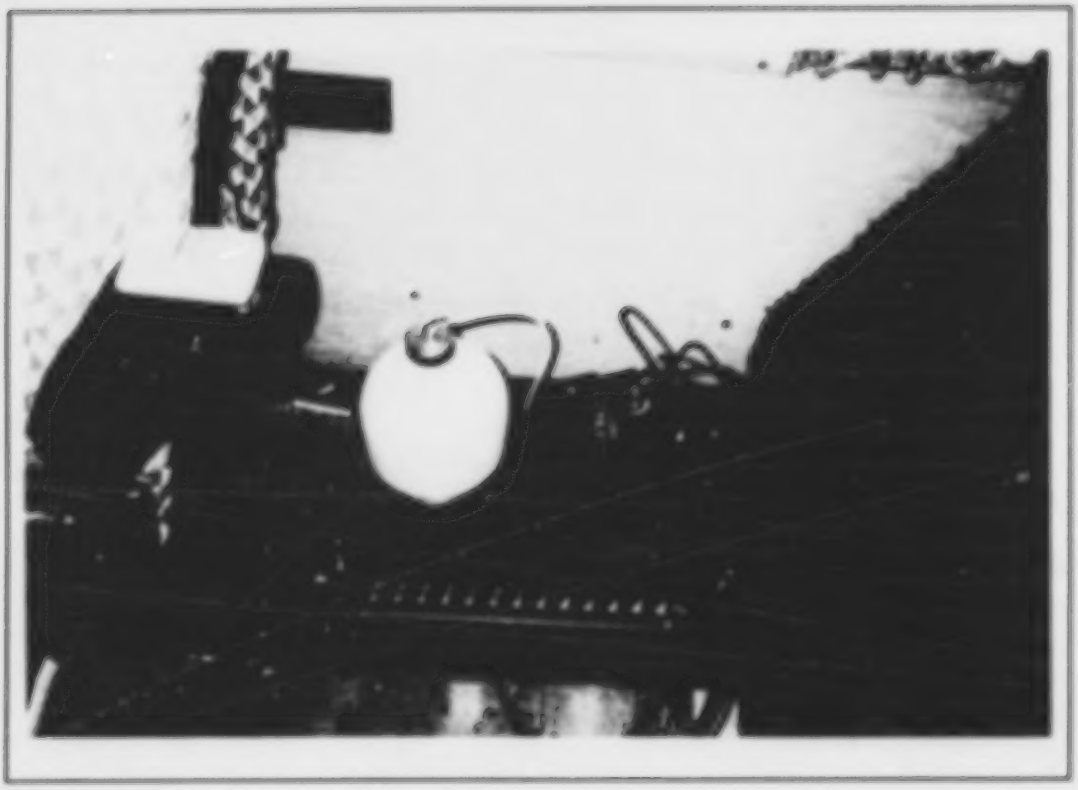
In those training scenarios where a real flame is not presented, the primary stimulus for signalling a fire is smoke. The smoke is generated at fixed locations, usually from one or two openings in a partial cabin or washroom mockup. Plate 4.13 shows a photograph of a mist-based smoke generator. The enclosures represented in the mock-ups generally included cabin, lavatory and galley portions of narrow body aircraft such as DC-9 or B-727 and wide body aircraft such as L-1011 and B-747.

The smoke is generated by a theatrical smoke generation unit, which produces a constant colour (generally white) and intensity smoke. In strategic locations, the presence of flames is simulated with flickering or static red lights. Plates 4.10 and 4.11 show two cages in the Lufthansa mock up of a cargo pallet. These contained a very effective system which appeared as a glowing fire with flames when activated.

In the more advanced training devices, fire extinguishers filled with compressed air are used to "extinguish" the simulated fire. Pressure sensitive switches or vanes detect the flow of the simulated extinguishing agent and the instructor or automatic shut off terminates the smoke

PLATE 4.13

CAA SMOKE GENERATOR



SOURCE: CAA FIRE SERVICE TRAINING SCHOOL, APS PHOTO

and flame generation. The Lufthansa facility made extensive use of this system.

4.3 Current Training Limitations

The limitations identified during the review were of two types. First, those identified by the industry in reference to the current practices and second, those identified by APS in view of the hypothesis.

The industry interviewees expressed concerns with respect to the following:

i) Usage of halon extinguishers, which left residue and produced toxic substances, causing discomfort among some trainees. The pollution factor necessitated a cleanup after each exercise.

ii) Use of a fire pit or burning rag, where the realism was limited to the appearance of a relatively constant size and characteristic flame and smoke.

iii) Inability to communicate effectively with other crew members while wearing the PBE. This concern originated with the observation that once a crew member donned the PBE, direct communication was difficult especially in view of the environmental noise and smoke which often accompany a fire incident.

iv) Cost of integrated training unit versus separate components. This issue involved provision of some training for smaller carriers through the use of components such as those described in (i) and (ii) rather than full-scale simulators, which would be available only to larger carriers.

v) Frequency of hands on training. This was limited due to economic reasons.

4.4 Additional Limitations of Current Training

APS identified further limitations in the realism and effectiveness of the current training. In general, it was evident that there is no diagnostic training and the devices used for the training offer somewhat unrealistic environments. Part of the problem lies in the technology used to generate smoke and in the absence of many currently available technologies to simulate cues for all of the elements to be simulated. The following list outlines the issues:

i) Smoke intensity and colour are variables and a function of the stage of the fire and the combustion material.

ii) Training to detect the satisfactory extinction of a fire is inadequate. The point of extinction of a fire, or the point at which the limited resource (fire extinguishing agent) need no longer be expended is not well defined. It should be noted that the philosophy of fire extinction is that "the fire is never completely out and that it cannot be left unattended even after it appears to have been extinguished." The issue here is that there is a limited amount of extinguishing agent on board the aircraft. How can it be optimally dispersed, given that fires may restart or propagate in different areas ?

iii) The range of scenarios which can be presented to the candidates in the current facilities is very limited. After a few visits to the facility, the

recurrent training is considered a repetition of previous exercises rather than a challenge with pedagogic or competency undertones.

iv) The evaluation of the performance of candidates is relatively subjective. The element of timing and progressive response is absent. In addition, in view of the concept of "optimal" application of the extinguishing agent, there is no feedback on the quantity utilized or "reserve power" availability.

v) Progressive fire fighting is not possible. The issue here is that a small fire may be extinguished with little intervention within a short period of time. Delays and/or inappropriate corrective action may produce larger and spreading fires which require other resources.

vi) Many of the cues for signalling fires, both visible and hidden, are not used in training.

5. LITERATURE REVIEW

A review of the pertinent documentation on topics relevant to a study of the development of a CABIN FIRE FIGHTING SIMULATOR was conducted.

First, we distinguish between IN-FLIGHT and POST-CRASH fires. In the case of in-flight fires, aviation fuels are generally not released in spills and outside fire fighting is not an option. In the case of post-crash fires both elements are a factor. Therefore, this review was limited to in-flight fires.

In-flight fires are presumed to occur in both:

(1) accessible areas such as galleys and toilets, permitting the possibility of quick extinguishment; and

(2) inaccessible areas such as behind panels, making extinguishment difficult. Both classes of in-flight fires have relatively low heat load and long time to flash-over compared to post-crash fires.

It was reported by the Ontario Research Foundation[1] in 1986 that there are "a wide variety of organic and polymeric substances capable of undergoing thermal decomposition and flaming combustion. These include structural and decorative moulded plastics, panelling and interior finishing, foam seat cushions, upholstery, carpets, blankets, luggage, natural and synthetic clothing, and a number of other materials. Most cabin interior materials are able to resist small ignition sources, but they readily decompose and burn when exposed to major fires."[1] This is supported by the National Fire Protection Association Code NFPA 402M-1984, the "Manual for Aircraft Rescue and Fire Fighting Operational Procedures." Although the Code discusses

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[1] Now known as ORTECH International.

mainly Ground-Based Fire Fighting, its conclusions are pertinent. They state:

"Regardless of ignition cause, aircraft cabin fires on the ground normally involve ordinary combustibles, such as cabin upholstery, panelling, refuse, paper towelling, and electrical insulation. The intensity of such a fire will depend on a number of variables; for example the time of discovery, the amount and form of materials ignited, the amount of air (oxygen) present, draft conditions, the involvement of other hazardous materials, (e.g. flammable liquids, oxygen, incendiary devices) and whether or not there was a delay in fire detection or fire suppression activity."

In any event, some causes of aircraft in-flight cabin fires are:[2]

1. Ignition (usually electrical in nature) from sources in the concealed spaces behind the cabin decorative liner or carried on board such as lighters, sprays etc. Such a fire can remain undetected for a considerable time and be beyond the control of hand fire extinguishers by the time it is discovered...

2. Cigarettes and other carelessly discarded smoking materials on aircraft seats, in trash bins, lavatories, galleys or receptacles not intended for the purpose.

The search focused on locating information relevant to the human factors associated with fire identification and "fighting." These included the appearance of smoke and fire, the appearance of material discolouration and associated deformation, smells and sounds and the tactile sensations associated with heat and smoke. Indeed, even chemical reactions associated with pyrolysis were reviewed for dominating species production. Furthermore,

the issues of breathing and respiration as points central to this simulation issue were also identified.

In one case, the issue of a fire that ignites behind a cabin panel was considered. In this case, as shown in Figure 5.1 (Fire Effects Emanating from Between Separations in Cabin Panels), smoke and other gases emanate from between the separations between cabin panels. The emanations may include smoke and gases, which could be toxic, although flames may not be visible. In this scenario, personnel required to combat the "fire" will have voice communication with one another and possibly with the flight crew, the ability to visually observe the progress of the fire effects, the sensations of smoke smell and inhalation and auditory stimulation associated with the fire.

An attempt was made to address the issue of the existence of American Society for Testing and Materials (ASTM) or National Fire Protection Association (NFPA) definitions that distinguish fire, smoke and other combustion or pyrolysis effects, by appearance and/or sensory classifications. No such details were found. In addition, a search for technically-detailed information related to in-flight cabin fires in the Technical Standard Orders (TSO) could not be located.

It was presumed that fire fighting associations have compendia of information on fire characteristics. Their literature, codes and standards were reviewed for relevance to the specification of a CABIN FIRE FIGHTING SIMULATOR. It seems that, at this time, there are no standards or classifications that describe smoke and fire. Nevertheless, ASTM Designation E176-88a, "Standard Terminology Relating to Fire Standards," does provide definitions relevant to the problem.

On the basis of the investigation, a MATRIX that shows the fire locations, the literature that covers information on fires at those locations, and the relevant human factors, was prepared.

Finally, for the record, it should be noted that generally more smoke is generated as a fire is extinguished than when it is burning profusely.

The following were undertaken:

Preparation of relevant information

- Document review
- Literature search to identify published information
- Identification of information that appeared relevant
- Review of information
- Identification of documents that bear directly on the issue
- Secondary sources
- Specifications provided by the documents

and discussions with:

- National Institute of Science and Technology;
- Federal Aviation Administration;
- Preparation of Source and Specifications Matrix
- General Discussion of Findings
- Discussion of Simulator
- Next Stages of Program

6. PREPARATION OF RELEVANT INFORMATION

On-Line and library research literature investigations were conducted. This effort was accompanied by telephone conversations with investigators at the National Institutes of Science and Technology, Gaithersburg, Maryland, USA, as well as a visit to the Federal Aviation Administration, Atlantic City, New Jersey, USA.

6.1 Document Review

6.1.1 Literature Search to Identify Published Information

The Fire Protection Handbook and National Fire Protection Association standards, and the set of ASTM standards were reviewed.

In addition to the NFPA "Handbook" and standards, and ASTM standards, fifty-two papers were identified by on-line literature searches.

Next, the references cited in the identified papers were considered for later study.

Then, during a visit to the FAA, in Atlantic City, additional published material was secured for review.

Other material was found from a variety of sources, and it too has been reviewed with a focus on in-flight fire simulation.

6.1.2 Identification of Information that Appeared Relevant

Several isolated portions of the "Handbook" and the standards are considered directly related to the Cabin Fire issue. In addition, of the fifty-two papers

identified, 51, produced during the period 1974 to date, were deemed to be within the scope of this study.

6.1.3 Review of Information

The NFPA publications and the 51 papers were examined in detail. The reduced list of 51 papers was further narrowed to sixteen on the basis of relevance.

6.1.4 Identification of Documents that Bear Directly on the Issue

The identified documents are cited in the reference list. Pertinent sections have been listed here and these include:

- Fire Protection Handbook, Sixteenth Edition, Edited by Cote, Arthur, F., and Linville, Jim L., National Fire Protection Association, Quincy, Massachusetts, 1986.

- "Human Behaviour and Fire," Section 1, Chapter 1.

- "Collecting Fire Data," Section 2, Chapter 2.

- "Aviation," Section 13, Chapter 1.

NFPA Standards:

- "Manual for Aircraft Rescue and Fire Fighting Operational Procedures," NFPA 402M-1984.

- "Manual on the Investigation of Fires of Electrical Origin," NFPA 907M-1983.

ASTM Standards:

- "Standard Terminology Relating to Fire Standards," E176-88a.

6.1.5 Sources Cited from the Literature

The gathered reports were reviewed in order to identify other information sources that could provide information.

6.1.6 Identification of Specifications Provided by the Documents

The specifications should be related to the information collected to report fires. The data are summarized by the NFPA in the Fire Protection Handbook.[3] As the documents states:

"A fire report is the written documentation that a fire occurred. It may be as brief as a basic fact statement or as lengthy as an extensive discussion of the fire, supported by photographs, witness statements, laboratory test results and physical evidence. The length and complexity of the report will depend upon the size and nature of the fire, the local fire service manager's need for specific data, and the resources available for obtaining information and completing reports.

The fire report should include, at some level of detail, a time staged description of the circumstances related to the initiation, discovery, growth and termination of the fire along with a description of the casualties and the damage resulting from the incident. The report should be

in the words of the fire officer and must be complete, so persons who were not at the fire scene can understand what happened."

Comparisons can be made because the NFPA Technical Committee on Fire Reporting has developed NFPA 901, "Uniform Coding for Fire Protection." Furthermore, there is a "Basic Incident Report" form shown in Figure 6.1 (Basic Incident Report Form), also developed by the committee. Regrettably, the report form contains no reference to human factors, colour of smoke, smoke intensity and flame colour/appearance.

6.2 Discussions

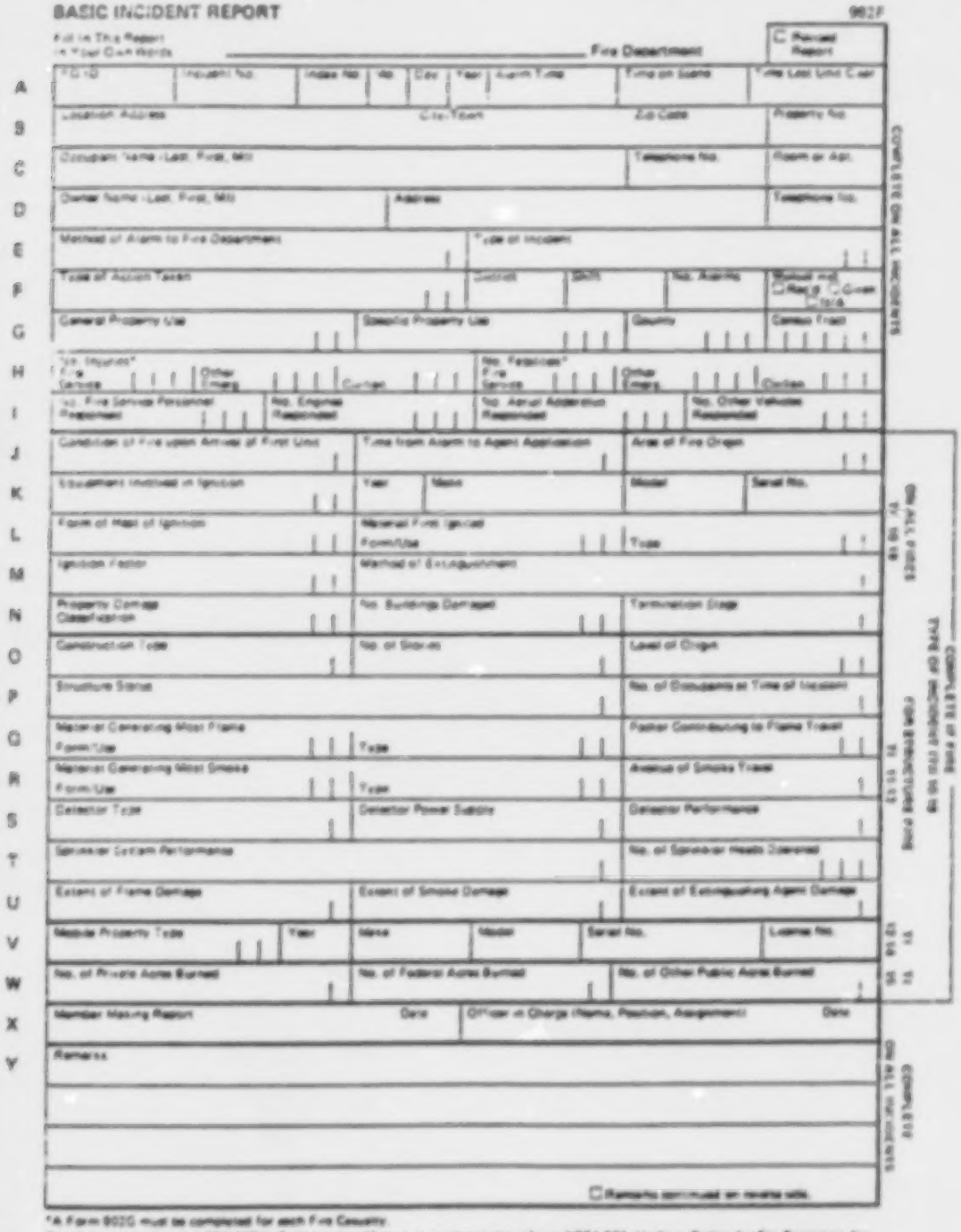
6.2.1 National Institutes of Science and Technology

Mr. J.G. Quintere, one of the authors of the identified documents, and Mr. W. Pitts, both of the National Institutes of Science and Technology were contacted.

6.2.2 Federal Aviation Administration

The FAA Fire Test Centre was visited on 20 June 1990. The visit included observation of the POST-CRASH simulation facility and viewing of test videotapes of a project aimed at experimentally determining the likelihood of fires in accessible areas of an aircraft and the hazards to cabin occupants from these fires. During the visit a discussion was held with Mr. C.P. "Gus" Sarkos of the Federal Aviation Administration, Atlantic City, New Jersey. Copies of AGARD papers related to the fire fighting issue were provided.

FIGURE 6.1
BASIC INCIDENT REPORT FORM



BASIC INCIDENT REPORT

9021

Fill in This Report in Your Own Words

_____ Fire Department

☐ Revised Report

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y

Alarm Time
Time on Scene
Time Last Unit Cleared
Location Address
City/Town
Zip Code
Property No.
Occupant Name (Last, First, MI)
Telephone No.
Room or Apt.
Owner Name (Last, First, MI)
Address
Telephone No.
Method of Alarm to Fire Department
Type of Incident
Type of Action Taken
Units
Shift
No. Alarms
Mutual Aid ☐ Rec'd ☐ Given ☐ N/A
General Property Use
Specific Property Use
Country
Census Tract
No. Injuries* Fire Service
Other Persons
Civilian
No. Fatalities* Fire Service
Other Persons
Civilian
No. Fire Service Personnel Responded
No. Engines Responded
No. Aerial Apparatus Responded
No. Other Vehicles Responded
Condition of Fire upon Arrival of First Unit
Time from Alarm to Agent Application
Area of Fire Origin
Equipment Involved in Ignition
Year
Make
Model
Serial No.
Form/Use
Type
Ignition Factor
Method of Extinguishment
Property Damage Classification
No. Buildings Damaged
Termination Stage
Construction Type
No. of Stories
Level of Origin
Structure Status
No. of Occupants at Time of Incident
Material Generating Most Flame
Factor Contributing to Flame Travel
Material Generating Most Smoke
Avenue of Smoke Travel
Detector Type
Detector Power Supply
Detector Performance
Sprinkler System Performance
No. of Sprinkler Heads Operated
Extent of Flame Damage
Extent of Smoke Damage
Extent of Extinguishing Agent Damage
Mobile Property Type
Year
Make
Model
Serial No.
License No.
No. of Private Acres Burned
No. of Federal Acres Burned
No. of Other Public Acres Burned
Member Making Report
Date
Officer in Charge (Name, Position, Assignment)
Date
Remarks
☐ Remarks continued on reverse side.

COMPLETE ON ALL INCIDENTS

COMPLETE ON FIRE OR EXPLOSION INCIDENTS

COMPLETE ON ALL FIRE INCIDENTS

COMPLETE ON ALL HAZARDOUS MATERIALS INCIDENTS

*A Form 9020 must be completed for each Fire Casualty.

This form is for use with NFPA 902M, *Field Incident Manual*. Users should also refer to NFPA 901, *Uniform Coding for Fire Protection*, for information on fire reporting systems and classifications for information entered on this form.

Source: NFPA

6.3 Preparation of Source and Specifications Matrix

A matrix has been prepared to show the fire effects that have to be simulated and the source information available reviewed for the several fire situations of interest here.

6.4 General Discussion of Findings

Findings show that human factors such as sound, skin sensations and smell have not been fully addressed. These could, however, be covered by preparation of new fire tests aimed at identifying the descriptions or by interviews with aircraft personnel who have experienced in-flight fires.

On the other hand there seems to be sufficient visual information to answer the questions relating to appearance of fire and smoke and their timing for various classes of in-flight fires.

7. SOURCES OF TECHNICAL INFORMATION

Technical information has been derived from four data sources, which are summarized below. The data sources are (1) National Fire Protection Association (NFPA) documents and other standards, (2) Technical reports, (3) FAA sources, and (4) other technical documents. The specific details are provided in Section 8 where the data are applied to the aircraft sections identified in the introduction.

7.1 National Fire Protection Association Documents

The National Fire Protection Association provides a database of current practice in the fields of fire prevention, fire suppression and fire fighting. The information is provided through the "Handbook" as well as through standards and other formats.

7.1.1 Fire Protection Handbook

Sections of the Fire Protection Handbook have been identified as relevant or related to this study.[4] The sections list some causes of aircraft cabin fires and describe briefly how the fires develop. Cited are electrical ignition behind the cabin liner, ignition due to post-crash fuel, cigarettes on aircraft seats, trash bins and such, and flammable liquids used when cleaning the cabin. Also included are photographs taken after actual fires. Furthermore, the section entitled "Aircraft Hand Fire Extinguishers" covers the types available and their effect on the user. Included are both water and Halon extinguishers. Nevertheless, few details are provided about the sensory effects of fire, and there is little quantitative information about the progress of fires.

7.1.2 NFPA Standards

NFPA 907M, the "Manual on the Investigation of Fires of Electrical Origin," discusses reporting on electrical fires. This code identifies the need to classify the electrical fires, electrical fire reports, and the equipment involved in ignition. This information may be useful during the evolution of a simulator design.

7.1.3 ASTM Standards

The set of ASTM Standards have been reviewed. Although they are useful for materials testing, they do not classify fire, smoke or human factors.

7.1.4 Other Technical Documents

Despite the wealth of technical information available, the boundary and initial conditions found in the literature may not simulate those found in aircraft.[2] Consequently, the results appear to be of little direct value. Furthermore, information on the human factor issue is only alluded to in passing and is not detailed or quantified in the available documents.

7.2 Technical Reports

Technical reports cover full-scale aircraft cabin fires in controlled environments as well as limited experimental trials focusing on issues such as seat material or panel fire.

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[2] For example, conditions of cabin airflow and pressurization are not replicated.

In some cases, such as for cargo area fires the data are directly useful. However, in the opinion of the consultants, the boundary and initial conditions do not simulate actual, in-flight, aircraft conditions.

7.2.1 Experimental Trials

Experimental trials have been performed in both full-scale and bench-top environments. Bench-top experiments do not appear to give data directly relevant to the specifications required for development of a fire-fighting simulator. Quintere provides a correlation between full and bench scale experiments.[5] This paper refers to ASTM E-84 fire spread classifications and discusses qualitative and quantitative values for time of fire growth and comparison with BS 476 PT 1 classifications.

7.2.2 Mathematical Models

Numerical aircraft fire simulations have also been reported. It is also the consultants' opinion here that the boundary conditions are sufficiently complex, varied and time dependant that a realistic model may not yet be available; the consultants concur with Sarkos that numerical modelling has not yet developed to the point that it can realistically predict actual in-flight cabin fires reliably.[6]

7.2.3 Fire Detection

A variety of detector scenarios have been reported in the references. These include several cases where the smoke detectors did not activate.

7.3 Information Provided by FAA

Ten in-flight hidden fire scenarios were examined by the FAA Test Centre in Atlantic City, NJ:[7]

- overheated wire bundles against insulation
- simulated dry arc tracking behind sidewall
- arcing wires against insulation in cheek area
- ignition of rigid foam ventilation duct under floor
- fuel soaked rags ignited in bottom of cheek area
- overheated ballast under stowage bin
- suitcase ignited in overhead stowage bin
- above ceiling fires of wire and insulation batts
- lavatory trash chute fires
- lavatory flush-motor fires.

The "test article" was a 13 m long aft section of a DC-10-30CF fuselage. Also provided were a set of AGARD articles from Conference Proceedings No. 467. Additionally, C. Sarkos informed us that the FIREMEN program has been terminated.[8]

7.3.1 Video Tape

The data reviewed was in the form of a videotape of selected sequences of the DC-10-30CF trials.[9]

7.3.2 AGARD Papers from the FAA

A set of FAA/AGARD papers was provided. They give background statistics supporting the need for fire research[10] and characteristics of transport aircraft fires in full-scale tests are described.[11] Once again, the work is aimed at post-crash fire investigation, but may be related to the in-flight fire case in terms of cabin fire behaviour under some conditions.

7.3.3 Technical Papers

Another technical paper was entitled "FAA Development of Improved Fire Test Requirements for Aircraft Interior Materials." It addresses test for seat materials, panels and other combustibles in aircraft cabins.[12] Once again, however, the focus was on post crash fires. Finally, work undertaken by DLR of West Germany was also referenced.

7.4 Other Technical Documents

The Transportation Development Centre (TDC) sponsored a study by the Ontario Research Foundation in 1986.[13] In this document, smoke mask evaluation criteria and test protocols were reported. These were based on the British Standards Institute (BSI) draft emergency escape mask specification and the U.S. FAA Standard Technical Order C99.

8. DETAILS OF AIRCRAFT IN-FLIGHT FIRES

A number of locations in the cabin of commercial aircraft present potential five sites. The locations considered in this study have been indicated on two diagrams of hypothetical aircraft. These are presented as Figure 8.1 and Figure 8.2. The former show the cross sectional area of a cabin while the latter shows the floor plan of a "combi" aircraft.

Findings regarding in-flight fires are summarized using the matrix shown in the CABIN FIRE CHARACTERISTICS MATRIX, shown in Table 8.1. The matrix is divided horizontally into the following aircraft regions:

(1) cabin area
(2) lavatory
(3) carry-on baggage
(4) cargo container
(5) behind galley
(7) ballasts

Under each horizontal sub-division we classify the characteristics observed as:

(a) fire[3]
(b) smoke/emissions
(c) sound
(d) temperature
(e) smell
(f) material

Each element of the matrix is filled, where possible, using information derived from the reference source material. In cases

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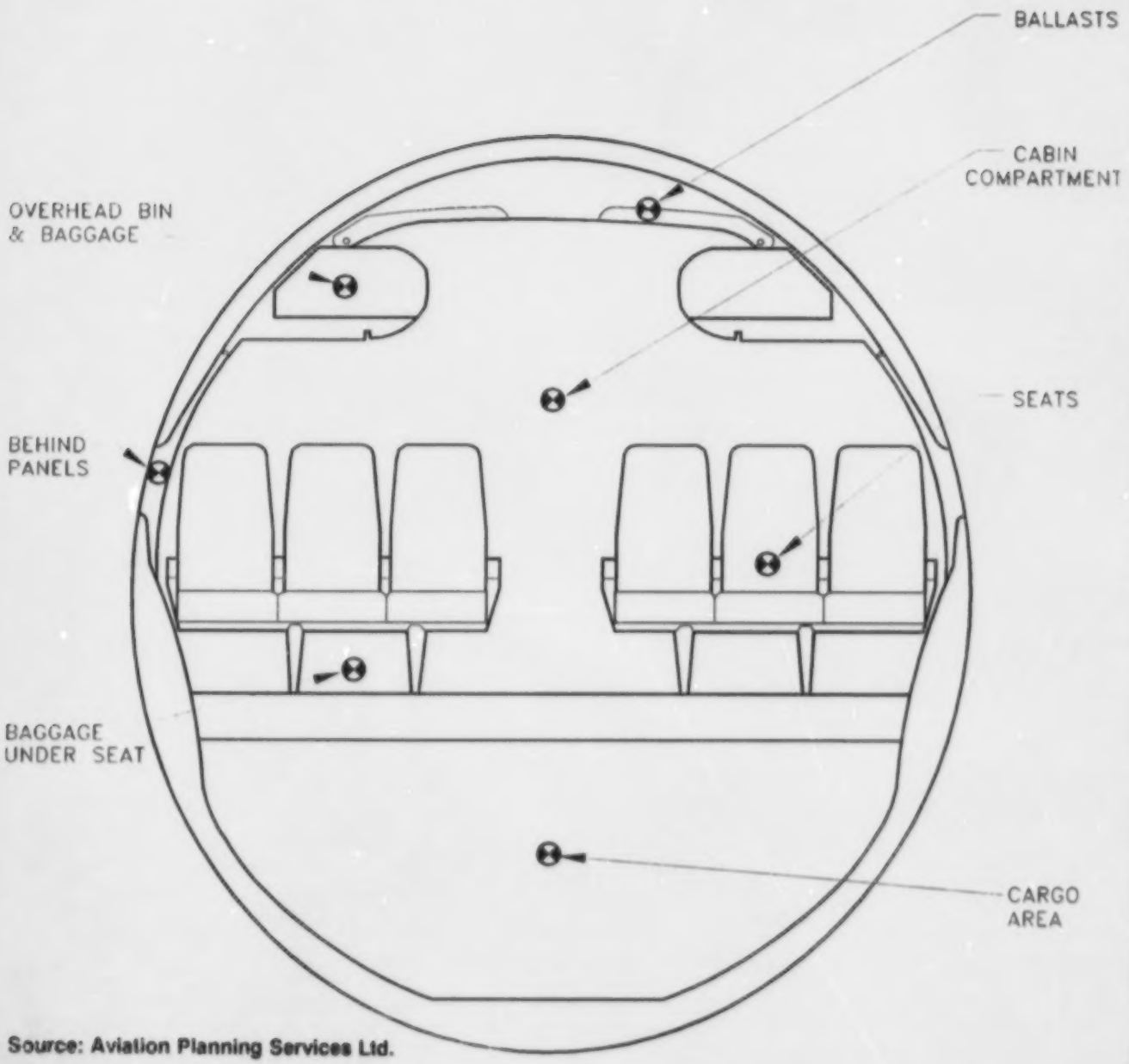
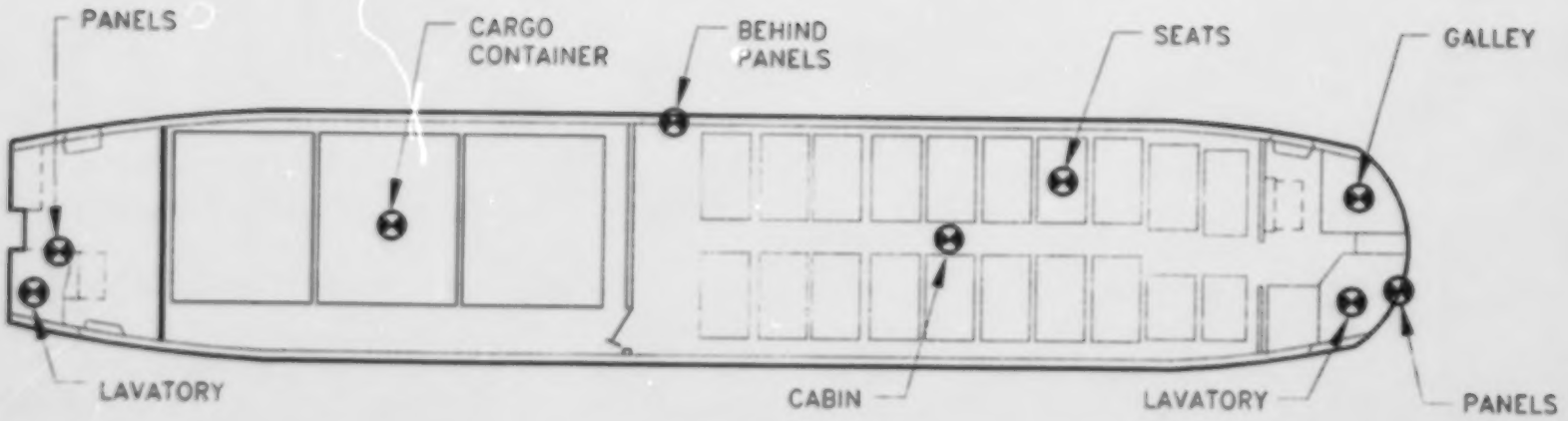
[3] The term "fire" is used in this report in two contexts. It refers to only the actual flames in one context and the total fire scenario in the other.

FIGURE 8.1
FIRE HAZARD AREAS CONSIDERED
CROSS SECTION VIEW OF AIRCRAFT



Source: Aviation Planning Services Ltd.

FIGURE 8.2
FIRE HAZARD AREAS CONSIDERED
FLOOR PLAN OF COMBI AIRCRAFT



Source: Aviation Planning Services Ltd.

TABLE 8.1
SOURCE AND SPECIFICATIONS MATRIX

	CABIN AREA		LAVATORY			CARRY ON BAGGAGE			GALLEY AREA			CARGO	
	SEATS	BEHIND PANELS	COMPARTMENT	BEHIND PANELS	CABIN EFFECTS	COMPARTMENT	UNDER SEAT	BIN	IN OVEN	OVEN AREA	OTHER	CONTAINER	BALLASTS
Flow	I (A)				I								
- Yellow		A	Q	A		no record			I (A)	no record	no record		A
- Orange		A	Q					Q - N					
- Red								Q - N					
- Length			Q - N	Q - N									
- Width			Q - N	Q - N				Q - N					
- Spread date	R		Q - N	Q - N			N	Q - N					
- Chronology	R	R	N	N			N	N				Q - N	
Smoke Emissions												N	
- White	A					no record				no record	no record		
- Yellow	A							Q				Q	A
- Blue		A	Q										
- Grey		A	Q					Q					
- Black								Q					
- Density	R		Q	Q - N	N		N		A			Q - N	
- Composition			N		Q		N	Q				N	
- Soot				Q - N	Q							Q	
- Location			Q - N	Q - N	Q - N			Q - N				Q - N	
Start		A	Q - N	Q - N	Q - N			Q - N				Q - N	
End		A	Q - N	Q - N	Q - N			Q - N				Q - N	
- Chronology		A	N	N	N			N					
Sound	A		no record	A	no record	no record	no record	no record	A	no record	no record	no record	A
- Hiss				A									A
- Snap				A					A				
- Crackle		A		A									
- Other													
Temperature	A	R	N	A	N	no record	N	no record	I (A)	no record	no record	N	A
Smell			R		no record	smoke smell	no record	no record	burnt food	no record	no record		
- Sharp		A		A								Q	A
- Acrid	A	A	Q	A									
- Foul				A									
Material		I (A)			no record	no record				no record	no record		no record
- Discoloration	Q		Q - N	Q - N			N	A	A			A	
- Deformation	Q		Q - N	Q - N				Q - N				Q - N	
- Decomposition			Q - N	Q - N				Q - N				Q - N	
- Struct. Damage			Q - N					Q - N	A			Q - N	
- Soot			Q - N	Q - N				A					

Legend:

I – Irrelevant; characteristic is not manifested
A – Assumed; matrix entry based on experience
R – Remarks; noted in source but not discussed
Q – Quotation; description provided without details
N – Numerical; quantitative data and/or time frame given

Source: Aviation Planning Services Analysis

where no data is explicitly available, but where information can be provided based on the expertise and experience of the consultants, the relevant matrix elements have been completed. This section describes the details in each area of the aircraft and the resultant specifications for each of the elements to be simulated (per section 3.4).

8.1 Cabin Area

Kuminecz and Bricker provide 25 large-scale flammability tests conducted in a Boeing 737 fuselage.[14] Seats, wall panel, ceiling panel and cabin panel are featured. Temperature, visibility, heat flux, air velocity, rate of fuel, seat weight loss, and concentrations of various gases are provided in an apparently comprehensive program that investigates fire propagation. Each cabin material individually and combinations of all materials were tested at 160 locations in cabin. The data are reported in 3000 curves over 600 graphs as well as 50 photos during and after the trials. Only two of these tests use a fully furnished cabin. The ignition source in these tests is a fuel pan placed under a seat (with varying amounts of fuel).[4]

Cabin and lavatory fires have also been simulated by Schutter, et al.[15] Two types of modern lavatory construction (labelled modules A and B) were tested in addition to a baseline test. The ignition source consisted of regular airline trash. Heat flux, temperatures, gas analyses, and physiological effects (EKG, respiration) were reported, but not interpreted.

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[4] Regrettably, C. Sarkos at the FAA indicated that he did not consider the trials representative due to their unrealistic boundary conditions.

In a study by McCaffrey, propane was used for a 1/2 scale simulation.[16] The work does provide some empirical equations. However, a review shows that the results are "not convincing." Nevertheless, this report does provide a set of cited references with information that may be relevant.

8.1.1 Seats

Fire

SPECIFICATION:	Seat fires are dominated by smoke effects with little flame visible.

The following notes are relevant:

- Sarkos, 990, p. 2[5] - states that "under the conditions of severe cabin fire, the foam core (of aircraft seats) ignites readily and burns rapidly, significantly contributing to the spread of the fire."

- NFPA, 1986, section 13, chapter 1, pp. 6-7 - states that discarded smoking materials are a major source for fires in seats. However, it is rare that the seat becomes actively involved (if so, conditions are usually unsurvivable).

- Sarkos, 1990, p. 3 - The improved seating materials (Vonar and Norfab) provided an additional available escape time of 60 and 43 seconds. These materials also provided greater improvements for in flight or ramp fires, preventing fires that may otherwise become out of control.

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[5] Details for the location of citations can be garnered from the references In Appendix B.

Smoke

SPECIFICATION:	probably white or yellow, developing smoke over 30 to 120 seconds.

- NFPA, 1984, p. 32 - points out that aircraft seating is usually made of polyurethane. Other furnishings can be made with vinyl. Both types of materials emit high concentrations of toxic gases when heated, which require breathing equipment to combat the fire.

Sound

SPECIFICATION:	low-grade hiss associated with pyrolysis. Probably eclipsed by other ambient noises.

Temperature

SPECIFICATION:	low, non-sensible temperatures.

Smell

SPECIFICATION:	foul, depending on seat material.

Material Deformation

SPECIFICATION:	actively burning material surface may shrink and/or liquefy and then be shrouded in smoke.

- Air Canada tapes - Seat covers and other synthetic materials are both class A and B fires because the material reverts to a liquid form before igniting.

Other

Relatively difficult to ignite.

8.1.2 **Behind Panels**

Fire

SPECIFICATION:	Yellow initially and then becomes orange on the periphery. Only visible at burnthrough, joints and openings.

- Sarkos, 1990, p. 4 - Aircraft fitted with noncombustible seat cushions would have a flashover caused by the burning panels.

- Sarkos, 1990, p. 5 - Using new composite materials for the panels, as opposed to earlier materials, showed significant improvements, adding 2 minutes before flashover for external fuel fires and actually preventing flashover for in-flight fires started from a gasoline drenched seat.

Smoke

SPECIFICATION:	blue/grey smoke, appears at joints and starts slowly. Billows and then attenuates as fire appears.

Sound

SPECIFICATION:	crackle.

Temperature

SPECIFICATION:	Sensible temperatures apparently originating overhead.

- Sarkos, 1990, p. 4 - states that the panels (side-walls, ceiling, stowage bins and partitions) are significant to the cabin fire load because of the large surface area and possibly location in upper cabin where temperatures are the highest.

Smell

SPECIFICATION:	foul and acrid smell associated with decomposition of plastics and resins.

Material

SPECIFICATION:	none

Other

May be necessary to break panel to combat fire.

8.2. Lavatory

Klinck identifies the characteristics of five fuel loads burned in a metal lavatory, using in-flight conditions with the Douglas Cabin Fire Simulator.[17] In 15 tests,the lavatory door remained closed for the 30 minute test period, in 15 others the door was opened after the fire had developed. The trails are recorded on colour film and air condition was sampled. In addition, material deformation and odour are described.

First, the lavatory door remained intact and additionally odours were identified and smoke density was discussed.

Three types of fuel were used in two quantities to ignite the fires: Airline trash, shredded paper and arson

attempt where airline trash was ignited with lighter fluid. The tests used animal subjects to determine biological effects.

Lavatory fires were also examined by Kourtides, et al.[18] Their baseline test used a burner to simulate lavatory fires. In order to calibrate the burner, some additional tests were performed with airline trash. With the burner in place, two tests were performed. First, a rapid growth fire with open door was simulated. Second, a similar fire was simulated but with a longer time of maximum fuel release. They identified "burn through time", rate of back face temperature rise, evaluation of selected combustible and toxic gases, heat flux rate, and structural integrity, providing a basic experimental background.

8.2.1 **Compartment**

Fire

SPECIFICATION:	Fires develop over 0 to 300 seconds, when they are observed as yellow plumes coming from container opening

- Klink, 1977, pp. 17-18 - provided data which depicted heat flux at different points on the lavatory door, wall and ceiling, as a function of time. These were provided for various fire loads with a closed door. The heat flux went as low as 1 W/cm^2 and reached local peaks as high as 30 W/cm^2. On the average, 5 or 6 W/cm^2 was a high value. Intense heat flux was located at the lower part of the lavatory door, reaching maximum values in the 200-300 second bracket.

- Klink, 1977 - In the baseline test, heat flux through the door reached higher heat flux values near the fire location (probably due to involvement of the edge blocking door jam material). Maximum was 8 W/cm^2 at 200 seconds and 20 W/cm^2 at 300 seconds.

- Klink, 1977, p. 46, baseline test with contemporary materials - At 254 seconds, flame appeared on the outside, increasing to maximum involvement of the door jamb at 300 seconds. There was a second period of activity between 1400 and 1900 seconds, located in the same area, with intensity of 1/4 to 1/2 of initial period (p. 46).

- Klink, 1977, p. 58 - The fire did not propagate in adjacent structures. Most materials resisted combustion. The polyurethane edge blocking material caused a second phase fire at the door jamb, where enough air was available to cause a severe localized fire.

- FAA tapes, test # 53 - Some flickering at 0:50 would indicate flame, but this did not show well in black and white. Flame appeared at 1:54, but disappeared soon after (1:58). Around 2:40, some flickering of flames was seen through cracks in the panel hiding a trash bin. Flames appeared to be involved throughout the hidden ompartment. But by 2:55, the smoke was dense enough for the flame not to be visible.

- FAA tapes, burner on trash bin - The trash ignited and started to burn actively at 0:08. Flames were bright yellow-orange. At 0:28, the fire was still contained in the bin. At 0:55, the source was

removed. Flames were out of the bin. Heavy flame production took place at 1:00. At 1:10, flames were reaching out of the trash bin and going up against the wall. At 1:20, the flames reached the ceiling. At 1:30, the fire was extinguished.

Smoke

SPECIFICATION:	A complex smoke history over 0 to 180 seconds, including a variety of fluid appearances, including billowing, streaming, hanging and diffusing.

- Klink, 1977, pp. 30-34, pp. 36-39, p.50 - In these tests, lavatory and cabin air gas analysis were performed as well as measurements of air content of hydrogen fluoride (HF), hydrodgen chloride (HCL), and hydrogen cyanide (HCN). Also, products of combustion were given on page 50 of reference.

- Schutter, 1980, pp. 16-17, table 1, plots 1-4 - Gas concentrations HCL, HCN and HF were provided. Module B was reported to produce the most HF and HCL and module A produced the most HCN. HF and HCL levels were caused by the type of decorative lining. HCN was mostly provoked by the polyamide foam used for the panels. Both modules produce comparable levels of O_2, CO, CH_4 and CO_2.

- FAA tapes, test # 53 - Hints of smoke appeared at 45 seconds. It was more distinguishable at 50 seconds. At 60 seconds, smoke was coming out from a definite general area, but there seemed to be no localized point of exit for the smoke -

it seemed that many openings were available for the smoke to escape. At 90 seconds, the presence of smoke was certainly noticeable as the rate of smoke production rose steadily. There was a uniform stream of smoke with some billowing coming out of all edges around 112 seconds. By 125 seconds, a layer of smoke occupied the top half of the lavatory. There was some turbulence in the smoke. At 150 seconds, the top half was densely filled and the bottom was partly filled with smoke. At 175 seconds, there was complete smoke obscuration, turbulence in circulating smoke could still be seen. However, at 190 seconds, the density was so high that nothing was seen, not even turbulence. Nothing took place again to 510 seconds when the smoke started to dissipate.

- FAA tapes, burner on trash bin - The smoke escaped from openings placed above the trash bin entrance at 28 seconds. The smoke was medium grey. At 48 seconds, smoke escaped from all joints, including under the sink counter top. Heavy smoke production took place at 60 seconds. At 90 seconds, the fire was extinguished, at which time, very large amounts of smoke and extinguisher were visible.

Sound

SPECIFICATIONS:	No sound record is available.

Temperature

SPECIFICATION:	Hot temperatures will be felt as radiant heat flux from the heat source.

- Kourtides, 1976, calibration tests - Within the first minute of the tests with the closed door, the module's surface temperature rose to 450°C with 2 bags of trash, and to 700°C with 3 bags. The temperature then decreased to 100°C in 7 and 9 minutes respectively.

- Kourtides, 1976, calibration tests - With the open door and 2 bags of trash, the temperature increased to 850°C in 1.5 minutes (with different results depending on how wide open the door was). Temperature then dropped to roughly 125°C within 12 minutes of ignition. With 3 bags of trash, temperatures rose to 1000°C on average in 2 minutes and decreased to 200°C at the end of 12 minutes.

- Kourtides, 1976, burner simulation - In test one, the unexposed surface temperatures on the panels reached peak temperatures after 3.5 to 5 minutes where the maximum was 450°C and the average was 200°C. After 12 minutes temperatures dropped to 50°C.

- Kourtides, 1976, burner simulation - In the first test, lavatory air temperatures reached peaks after 2 minutes and ranged between 350°C and 750°C. Temperatures dropped to 50°C and 200°C after 12 minutes.

- Kourtides, 1976, burner simulation - In test two, peak temperatures of the unexposed surfaces reached peaks ranging from 100°C to 450°C after 3 to 4 minutes. At the end of 7 minutes, temperatures ranged between 20°C and 200°C.

- Kourtides, 1976, burner simulation - In test two, lavatory air temperatures peaked at 2.5 minutes, ranging from 200°C to 800°C. They then dropped within 100°C and 300°C after 6 minutes.

- Schutter, 1980, p. 21 - Fire intensity was measured using exhaust temperature. The exhaust temperature reached maximums between 875°C and 950°C within 1,200 seconds. Module A had the more intense fire, peaking earlier than the other module (within 880 seconds).

- Schutter, 1980 - For the most part (module A), the charts indicated a rapid lavatory air temperature rise to ~500°C in the first 50 seconds, climbing up to 800°C to 1000°C within 200 to 600 seconds, remaining at that peak for roughly 200 seconds. In the following minutes, the air temperature decreased gradually to below 300°C. Of course, air temperatures varied with location within the lavatory, but all thermocouples showed similar behaviour with variation on time. At times, there were local fluctuations of 50°C to 100°C with durations within 50 seconds.

- Schutter, 1980 - For the surface temperatures of module A, they gradually climbed to a maximum of 400°C between 300 and 500 seconds. At that point, temperature decreased gradually over the

test period, reaching 100°C after 2000 seconds and levelling off to 50°C at the end of 3600 seconds.

- Schutter, 1980 - For the most part (module B), the charts indicated a rapid lavatory air temperature rise to approximately 400°C in the first 50 seconds, climbing up to 600°C to 700°C within 100 to 300 seconds, remaining at that peak for roughly 200 seconds. In the following minutes, the air temperature decreased gradually to below 300°C (roughly 2500 seconds) levelling off to 100°C by the end of the test. Of course, air temperatures varied with location within the lavatory, but all thermocouples showed similar behaviour with variation on time.

- Schutter, 1980 - For the surface temperatures of module B, they gradually climbed to a maximum of 200°C to 300°C between 400 and 500 seconds, sometimes taking as long as 1000 seconds to reach a maximum. At that point, temperature decreased gradually over the test period, reaching 150°C after 2000 seconds and levelling off to 50°C at the end of 3600 seconds.

Smell

SPECIFICATION:	Acrid odour.

- Klinck, 1977, p. 40 - In both the open and closed door lavatory tests, an objectionable odour was noted.

- Klink, 1977, p. 53 - There was also a strong residual odour of phenolic resin.

Material Deformation

SPECIFICATION:	Delamination.

- Klink, 1977, p. 46, baseline test with contemporary materials - At 190 seconds after ignition, there was decomposition of exterior laminate concentrated at lower right hand portion of door.

- Klink, 1977, p. 53 - The laminate in the door area and wash stand were thermally shrunken but not decomposed. Adjacent damage to aft bulkhead (lower area). Splitting and shrinking of laminate. Decomposition of polyurethane edge. The door was fused shut by the polyurethane edge blocking. Discoloration of adjacent module panel but no effect on it's inner surface. The weight loss was 23.58%.

- Klink, 1977, p. 58 - Noted also is that the decorative laminate split and shrank rather than burn when exposed to heat.

- Kourtides, 1976, burner simulation - At the end of the first test, no actual burn through occurred. Panels were completely charred and delaminated on the interior. Extensive charring took place in the exterior. Charring was observed after the first minute.

- Kourtides, 1976, burner simulation - Test two had flame burn through at the ceiling wall corner at just under 3 minutes. There was a structural joint failure. There was a noted

temperature rise on the back-face of the panels. Flame burn through due to decomposition of material or severe distortion.

- Schutter, 1980, p. 15 - Particulars in test module A are that the hinges came loose, thus allowing the door to be displaced downwards. Therefore a draft was created and the fire was involved in the full height of the module. Core shrinkage took place, thus increasing heat transmission. Adjacent aft bulkhead showed discoloration. Damage to ceiling, back and floor panels was limited to the melting of wire insulation and reticulation of the core with some surface discoloration. Resin burnout was extensive in the interior of the lavatory. Complete burnout in the case of the washstand side and inner door surface.

- Schutter, 1980, p. 16 - Particulars in test module B are as follows. Exterior damage was limited to local areas of the decorative laminate indicating interior fire mainly limited to lower third of lavatory. The washstand side panel was warped inward, and as a result, actually reduced the fire activity in the upper part. The floor was extensively damaged. Only the decorative laminate was damaged on the ceiling.

- Schutter, 1980, p. 22 - The average material weight loss within the lavatory ranges between 26 and 29 percent. Some of the loss

resulted in ash and residuals inside the lavatory.

- Schutter, 1980, appendices - Photographs of the burn tests were provided. Shrinkage causing block grid lines (p. 1-9) can be clearly seen. Other post fire damage was shown on the pages following the grid lines.

- FAA tapes, burner on trash bin - At 1:00 minute into the test, charred trash started to escape from the bin and sooting took place.

- FAA tapes, burner on trash bin - Charring of the surface in contact with the flames took place at 1:15.

Other

- Klink, 1977, p. 50, p. 58 - The closed door was effective when containing lavatory combustion gases.

- NFPA, 1986, section 13, chapter 1, p. 6 - stated that many lavatory fires were caused by discarded smoking materials, such as cigarettes, in trash bins.

- Klink, 1977, p. 57 - The thermal hazard is proportional to the fuel quantity up to the point where the air fuel mix is fuel rich. A fuel rich fire burns at a constant rate for a longer time. However the fuel distribution is also of great importance, mostly when concerned with intensity at local points.

- Klinck, 1977, pp. 14-15 - It was noted that opening the lavatory door provokes an increased heat flux at the ceiling of the lavatory. Cabin temperature also rose significantly.

- Klink, 1977, p. 57 - Opening the door did not make environment unsurvivable although the flight attendant would need thermal protection in order to combat the fire. Opening the door does present a threat to the overhead ceiling panels and creates more smoke at a much earlier time.

8.2.2 **Behind Panels**

Fire

SPECIFICATION:	Yellow flames over 60 to 300 seconds.

- FAA tapes, Lavatory test #54 - The fire was set behind the lavatory panels, directly behind the toilet. At 1:10, flames appeared along the vertical left corner joint. Flames came out in bursts. At 1:13, there was constant visible involvement, still on the left side. The flames disappeared at 1:20. Flickering flames appeared at 1:30. At 1:40, the flame was no longer visible. At 2:46, flames flickered intermittently at various locations on the joints. Steady flames were visible at 3:05. At 3:30, the flames were no longer visible.

- FAA tapes, Lavatory test #56 - Fire was set behind the back wall panel, behind the toilet. Flames

appeared at 0:45 alongside the joint. At 0:55, flames were spread along 1/4 width of the lavatory back panel, reaching 0.5 m high. Flames still visible as before at 1:10. By 1:20, flames died down but remained visible. Flames picked up again at 1:35, breaking through bottom joint. The bottom flames disappeared at 1:40. At 2:10, the toilet seat was involved, reaching maximum intensity within the following minute. Constant burning of the panel and seat were still in place at 4 minutes. Seat involvement increased at 7:15. At 8:00, the ceiling was actively involved for a while.

Smoke

SPECIFICATION:	A complex smoke history, ranging from thin, barely noticeable smoke to thick dark plumes over 30 to 300 seconds. In addition, there is "flying soot" in the atmosphere.

- FAA tapes, Lavatory test #54 - The fire was set behind the lavatory panels, directly behind the toilet. Smoke started escaping the mid section joint just above the toilet. The smoke was very thin and barely noticeable at 0:38. Around 0:45, the smoke is more visible, concentrated at the left of the joint. At 1 minute, a thin layer started to accumulate at the top of the lavatory. Smoke is now escaping throughout the midsection joint. At 1:10, large puffs of smoke escape. By 1:20, the smoke has filled the top half of the lavatory. The density is high but we can still see circulation in the smoke. Smoke continues to escape through the midsection joint. At 1:40, the smoke was escaping at an

accelerated rate. At 1:45, smoke appeared near floor joint. At 2:00, the top half of the lavatory was densely filled with smoke and the bottom half has a light haze. The smoke layer was slowly expanding downwards. The lavatory was completely smoke filled at 3 minutes. Smoke turbulence was still visible. At 4:05, a burst in current seemed to have moved the smoke such that visibility was null throughout the lavatory. Turbulence could no longer be seen. The smoke eased around 6:00, when the toilet became visible. At 7:00, the back panel became visible.

- FAA tapes, Lavatory test #56 - Fire was set behind the back wall panel, behind the toilet. Smoke appeared at the midsection joint at 0:30. A light plume of smoke rose from the left side. Smoke appeared at the right side at 0:50. At 1:20, the smoke layer had filled the top half of the lavatory. Smoke appeared through bottom joint at 1:35. By the 4 minute mark, the lavatory was filled up with smoke. Turbulence was seen. Density was not so high that we could not distinguish the burning seat. Smoke density was constant but relatively thin at the 8 minute mark. There was a hole in the middle of the wall panel - lining appeared to have been hanging there. In the last 3 minutes, only the seat appeared to have been involved. Soot was flying around until the end.

- FAA tapes, Lavatory test #54 - Flying soot appeared at 2:46. At 3:30, about 5 pieces of soot were seen flying around for a while.

- FAA tapes, Lavatory test #56 - At 4:00 flying soot started to appear. Soot was still flying about at the 5 minute mark as there were roughly 10 to 20 pieces of soot in that air at a time.

Sound

SPECIFICATION:	Crackling and snapping as associated with electrical fires, followed by hiss.

Temperature

SPECIFICATION:	Panels are warm to the touch, but the heat is non localizable.

Smell

SPECIFICATION:	Sharp, acrid, foul, resinous smell associated with electrical insulations.

Material

SPECIFICATION:	Charring and delamination.

- FAA tapes, Lavatory test #54 - The panel started to char at 1:20, spreading with time. Delamination and charring covered the bottom left corner .15 m wide and .25 m high. At the end of 7 minutes, one could distinguish the back panel where there was delamination on the bottom left of the top wall panel, covering an area of 0.6 m by 0.6 m.

- FAA tapes, Lavatory test #56 - Delamination and charring started at 0:50. Charring reached an

area of 0.6 m x 0.6 m x 1:05. By 1:10, decorative lining had burned up in that area. Wall surfaces appeared to be completely charred although it was hard to see with the smoke obscuration.

- FAA tapes, Lavatory test #56 - At 6:40, some burning pieces of material fell to the ground. There were about 2.5 pieces a second lasting for times of 5 seconds with breaks in activity of 3 or 4 seconds. Falling burning material had slowed down to one piece every now and then by 8 minutes.

Other

- NFPA, 1986, section 13, chapter 1, p. 6 - Such fires were usually electrical in nature and burn undetected for a considerable amount of time (45 min.), by which time they are beyond control.

8.2.3 **Cabin Effects**

Little direct data was available on cabin effects.

Fire

No observable flames during period of trial.

Smoke

SPECIFICATION:	A stratified smoke environment, becoming complex as the ventilation system effects its movement. This is coupled with some baseline sooting.

- Klink, 1977, p. 52 - Smoke density within the cabin for the baseline case was provided. However, on all of these charts, the print was too small to be legible.

- Klinck, 1977, p. 40 - When lavatory tests were performed, some observations were made on the cabin environment. Noted was minimal smoke density (although some obscuration) when the door was left closed. When the door was opened, there was an 18" thick layer of smoke progressing rapidly along the ceiling towards the air lock. It then cascaded down the wall, obscuring visibility for 20 to 40 seconds. The layer was then displaced uniformly down with clear visibility above. Ventilation finally mixed smoke and visibility was obscured again.

- Schutter, 1980, p. 17, plot 5 - Module A had a higher smoke density due to failure of the door hinges allowing more smoke to escape. Maximum density occurred farthest from the module since the smoke travelled along the ceiling and was deflected downwards at the back of the module. Tests indicate that passenger visibility would be impaired 200 seconds after ignition. There was approximately 80% to 90% light transmission after 200 seconds, reaching 25% to 60% transmission after 600 seconds (module A being the worst).

- Schutter, 1980 - For Module A, the light transmission was near 100% up to 250 seconds near the lavatory and up to 90 seconds near the back of the cabin. Visibility dropped to 40% near the lavatory and 20% at the back at the end of 400 seconds. Visibility then stabilized for the most part,

although light transmission near the lavatory dropped another 10% by the end of 400 seconds. Visibility then started to improve at a constant rate reaching values around 90% visibility at the end of 1800 seconds (worst visibility near lavatory, second worst near back of cabin). By the end of the test (3600 seconds) visibility was back at 100% except near the lavatory.

- Schutter, 1980 - For module B, the light transmission was near 100% up to 300 seconds. There were many fluctuations such that visibility would drop to 90% for periods of a few tens of seconds. The best area was in the middle of the cabin. The front and back of the cabin had roughly equivalent smoke densities. Visibility dropped gradually to 20% at the extremities and 40% in the centre within 2100 seconds. Visibility then gradually increased by 20% by the end of the 3600 seconds.

- Klinck, 1977, p. 40 - Animal respiration amplitude increased with asphyxiants and decreased with irritants. Airline trash seemed to cause more irritants.

- Klink, 1977, p. 53 - Animals kept a few feet away from the door had soot deposit on their fur.

Sound

SPECIFICATIONS:	hiss

- Based on consultants opinion.

Temperature

SPECIFICATIONS:	Temperatures slightly above ambient.

- Kourtides, 1976, burner simulation - In the first test, air temperatures outside of the lavatory reached 40°C after 3 minutes and stabilized at that point.

- Kourtides, 1976, burner simulation - In test two, exterior temperatures reached excessively high values between 2 and 3.5 minutes, peaking at 100°C. After 3.5 minutes, air temperature stabilizes at around 50°C.

- Schutter, 1980, p. 21 - Cabin temperatures reached maximums of 44°C to 51°C near the animal cage (shielded and a few feet from the door), and 43°C to 61°C on thermocouple 24 (unshielded and a few feet from the door).

- Schutter, 1980 - For module A, cabin temperatures climbed steadily to 40°C within the first 600 seconds and peaked at 55°C at 1200 seconds. After that, the temperatures slowly declined to roughly 30°C at the end of 3600 seconds. Of course, temperatures near the lavatory were more erratic, reaching local peaks of 100°C but for short periods of time.

- Schutter, 1980 - For module B, cabin temperatures climbed steadily to 40°C within the first 1200 seconds and levelled off at that temperature until time 2400 seconds. After that, the temperatures slowly declined to roughly 30°C at the end of 3600

seconds. In that case, the entire cabin was under the same temperature conditions (within a few degrees).

Smell

SPECIFICATIONS:	acrid smoke smell.

- Based on the opinion of the consultants.

Material

SPECIFICATIONS:	none required.

- Not applicable.

8.3. Carry On Baggage

8.3.1 Compartment

The consultants suggest the following:

Fire

SPECIFICATION:	After 60 seconds.

Smoke

SPECIFICATION:	White over 120 seconds.

Sound

SPECIFICATION:	None.

Temperature

SPECIFICATION:	Hot to warm.

Smell

SPECIFICATION:	Smoke smell.

- Blake, 1983, case history - During cruise, passenger repcrted smell of smoke traced to another passenger's cabin baggage. Source was matches. Fire was extinguished in flight.

Material

Other

8.3.2 Under Seat

Fire

SPECIFICATION:	No visible flames over 5 minutes, although heating effects are felt.

- Kuminecz, 1982, figures 572 to 573 - In general heat fluxes away from the source rise slowly in the first 4 to 5 minutes reaching values below 1,135 J/m^2 (0.1 BTU/Sq.Ft.). In some areas, they will not exceed 2,270 J/m^2 (0.2 BTU/Sq.Ft.) for the entire test period. However, in some cases, they will rise to 11,350 J/m^2 (1 BTU/Sq.Ft.) by the 6 minute mark. They will only start to decrease after 10 minutes into t' e test, reaching 5,680 J/m^2 (0.5 BTU/Sq.Ft.) by the end of the test. Nearer to the

fire, heat flux is more erratic, peaking as high as 51,000 J/m^2 (4.5 BTU/Sq. Ft.).

- Kuminecz, 1982, figures 698 to 697 - Heat fluxes are available for only the first 6 minutes in this test. In general heat fluxes away from the source rise slowly in the first 2 to 4 minutes reaching values between 2,840 J/m^2 (.25) and 17,000 J/m^2 (1.5 BTU/Sq. Ft.). They will start to decrease after the 4 minute mark, reaching values below 11,350 J/m^2 (1 BTU/Sq. Ft.) by the end of the sampling. Nearer to the fire, heat flux is more erratic, peaking as high as 12,500 J/m^2 (11 BTU/Sq. Ft.).

Smoke

SPECIFICATION:	Abrupt changes in light transmission at 30 seconds.

- Kuminecz, 1982, figure 571 - Light transmission is 100% for times ranging between 30 seconds and a minute. They rapidly drop to zero by 1 to 4 minutes and stay there until the 8 minute mark. After that they indicate a sign of rising, but there isn't any data after 8:30.

- Kuminecz, 1982, figure 696 - Light transmission is 100% for times ranging between 30 seconds and a minute. They rapidly drop to zero by the 2 minute mark and stay there until the end of the test.

- Kuminecz, 1982, figures 576 to 586 and 700 to 710 - Gas concentrations are provided for hydrogen cyanide, hydrogen fluoride, hydrogen chloride, carbon monoxide, carbon dioxide, oxygen and hydrocarbons.

Temperature

SPECIFICATIONS:	Thermal range from ambient to 500C over 5 minutes.

- Kuminecz, 1982, figure 547 to 553 - Cabin temperatures remain at ambient levels for times ranging from 20 seconds to 4 minutes. At the four minute mark, the maximum registered temperature is 75°C. Temperatures rise sharply to 125°C to 450°C by 7 minutes. Then, levels generally start to drop slightly, reaching 110°C to 325°C at the end of the 14 minute test.

- Kuminecz, 1982, figure 671 to 677 - Cabin temperatures remained at ambient levels for times ranging from 30 to 45 seconds. Temperatures rose sharply to 200°C to 500°C by 4 minutes. Then, levels generally started to drop slightly, reaching 125°C to 250°C at the end of the 14 minute test.

- Kuminecz, 1982, figure 556 to 558 - Ceiling temperatures were close to ambient temperatures for the first five minutes. At the five minute mark, they rose steadily to values ranging from 500°C and 800°C at the end of 14 minutes. Further away from the source of fire, the ceiling temperatures did not climb as high. They would reach values ranging from 100°C to 600°C at the end of 5 minutes, finishing the 14 minute mark at 200°C to 400°C.

- Kuminecz, 1982, figure 680 to 682 - Ceiling temperatures were close to ambient temperatures for the first 2 minutes. At the four minute mark, they rose rapidly to values ranging from 700°C and 900°C. These peaks held for roughly 2 minutes and

then dropped 300°C. After that, the temperatures started a slow decline reaching a range of 200°C to 400°C at the end of 14 minutes. Points further away from the source of fire held the lower temperature ranges although the curves have the same general shape no matter where the sampling was performed.

- Kuminecz, 1982, figures 559 to 562 - Upper sidewall temperatures were close to ambient temperatures for the first 3 minutes. After that, they climbed as high as 750°C with a minimum of 450°C at the end of 6 minutes. At 14 minutes, they descended to 400°C to 500°C. For the lower sidewalls, the temperatures only reached 300°C to 600°C at the end of 10 minutes, maintaining those temperatures up to the 14 minute mark.

- Kuminecz, 1982, figures 683 to 686 - Upper sidewall temperatures were close to ambient temperatures for the first minute or so. After that, they climbed as high as 800°C at the end of 3 minutes. At 14 minutes, they descended to 500°C to 600°C. For the lower sidewalls, the temperatures only reached 300°C to 600°C at the end of 6 minutes, maintaining those temperatures up to the 14 minute mark.

- Kuminecz, 1982, figures 563 to 567 - Seat cushion temperatures will varied between ambient and 100°C for times ranging from 30 seconds to 9 minutes. After which, the temperature would jump sharply to 500°C - 800°C, stabilizing at those high values. The time at which the jump took place depended on the location on the seat cushion.

- Kuminecz, 1982, figures 687 to 691 - Seat cushion temperatures varied between ambient and 100°C for times ranging from 30 seconds to 3 minutes. After which, the temperature would jump sharply to 700°C - 800°C, stabilizing at those high values. The time at which the jump took place depended on the location on the seat cushion.

Smell

None Available

Material

SPECIFICATION:	Unperceptible decomposition.

- Kuminecz, 1982, pp. 22-23 - Presents the weight loss of materials as a percentage of initial weight. Note that for some materials, such as the seats, the data is not available.

8.3.3 **Bin**

Fire

SPECIFICATION:	Yellow flames appearing at about 9 seconds with growth and flicker time proceeds.

- FAA tape, test #30 - Flames appeared after 9 seconds. They were localized, appearing through the top edge of the bin door. The flame appeared to be yellow at this time. It was flickering and disappeared from sight every now and then. The flames continued behaving as such, but slightly more intense. By 20 seconds, the flames were no longer visible. At 1:37, flames

appeared through the smoke - same type of flickering as before, although more intense. At 2:20, the flames were constant. The involved area was wider but still localized at the upper edge of the bin. Colour looked yellow through the smoke. The flames reached higher at this point, indicating a more intense fire. By 2:40, the flames become orange. By 3:00 minutes, the flame had intensified - about 0.25 m wide and 0.2 m high at the bin's top edge. From careful inspection, the flames seemed to have reduced slightly in intensity, yet they were still going on at the 5 minute mark. Flame was still orange at 5:25. At 5:45, flames appeared at bottom right corner of bin door. By 5:52, the entire lower part of the bin was involved. Flames 0.075 m high appeared right across the bottom edge of the bin.

- FAA tape, test #30 (different view) - Flickering flames appeared white-yellow at 17 seconds. They were 0.05 m to 0.075 m wide, 0.025 m high, located at the central part of the top bin through the door's edge. Flames were no longer visible at 30 seconds. Flames appeared again at 1:38. They were more intense, 0.13 m high and 0.2 m wide, flickering yet always visible. The colour appeared to have turned orange with a black centre. By 1:43, the colour became pale yellow. At 1:50, the flames disappeared. The fire reappeared at 2:10, with the same intensity as before. The flame was orange with a yellow core, reaching 0.38 high at 2:18. The involved area spread along the top edge of the bin door, reaching 0.5 m wide by 2:31. However, the intensity was the highest at the point of original burn-through. Flames reached highest intensity yet at the 3 minute mark, reaching 0.5 m high over the involved area. The flames were licking at the ceiling. The flame's yellow core was about 0.5 m by 0.5 m and an

orange flame filled the remaining fire volume. The fire intensity stayed at that level up to 5:20. At 5:20, the flame seemed to pick up with more rapid flickering. The involved area was roughly 0.5 m wide along the bin's top edge, with 0.5 m high orange flames. At 6:03, the entire bottom edge was involved as flames were bursting out 0.5 m downwards right across the bin's bottom edge. At 6:20, the entire top portion was involved, 0.5 m high across. There seemed to be less visible activity at the bottom. At 6:35, there was involvement right around the bin door's edge. At 6:48, there was no longer any sign of flame. There was a hint of flame (smouldering combustion) inside the remaining bin at 6:55.

Smoke

SPECIFICATION:	Thin, blue-grey smoke at about 17 seconds, concentrated in the upper half of the cabin. By 90 seconds the entire cabin is smoke-filled.

- FAA tape, test #30 - After 17 seconds, thin smoke started to appear rising to the ceiling. 2 seconds afterwards, there was a steady stream of light smoke escaping from the bin door's top edge. At 20 seconds, smoke appeared to be blue-grey, of constant density. By 35 seconds, the situation seemed to have improved since there were no flames nor any apparent increase in smoke density. However, at the 50 seconds mark, smoke was streaming visibly out of the bin. There was an accelerated increase in smoke density. By one minute, the bin involved was only partially visible. Smoke was still concentrated in the upper half portion of the cabin. By 1:26, the entire cabin is smoke filled, although the highest density remained near the bin.

Smoke appeared to be more on the grey side. At this point in time, smoke was circulating according to ventilation as there was visible motion within the smoke. After 2 minutes, the cabin was completely obscured. Smoke seemed to be mainly light grey with blue and white layers. At 2:40, the smoke density decreased slightly such that we could distinguish some of the adjacent bins. By 4:45, the smoke density rose again to the point where the flame was almost no longer visible. At 5:25, the smoke intensity was the same as that at the 4:45 mark.

- FAA tape, test #30 (different view) - Plumes of blue-grey smoke appeared through top edge at 25 seconds. Smoke density increased slowly at a constant rate. There was some black smoke. At 50 seconds, the smoke was dark grey. At the one minute mark, smoke production increased, although there was no obscuration yet. There was a thin haze at the top portion of the cabin. Smoke was still coming out of the top edge of the bin at a constant rate, although bellowing occasionally. At 1:30, obscuration took place: the bin was only partially visible with smoke concentration still near the cabin ceiling. At 1:50, the smoke was billowing intensely. The top portion of the cabin was obscured. The smoke was dark grey. At 2:07, the cabin was almost completely obscured. At 2:30, the smoke density eased as we could distinguish the bin. At 3:30, obscuration increased again. The bin was barely visible at 3:50 although the flame still showed through. The smoke was now medium grey. At 5:56, a narrow stream of white fumes (1" diameter) fell from a few places along the bottom edge of the bin. The cabin was still completely obscured at 6:48, with medium grey smoke.

- FAA tape, test #30 (different view) - There was some soot flying around at the 6:48 mark.

Sound

SPECIFICATION:	Low hiss growing to roar.

Temperature

SPECIFICATION:	Heat felt by skin.

Smell

SPECIFICATION:	Carboniferous smoke.

Material

SPECIFICATION:	No burn effects of material over the 5 minute period; material effects may be neglected.

- FAA tape, test #30 - Around 5:25, pieces of burning material fell from the upper bin level to the floor. About 5 pieces fell in the following 5 to 10 seconds. More material fallout occurred at 6 minutes. The pieces were smaller but in greater quantity, somewhat like sparks falling to the floor.

- FAA tape, test #30 (different view) - There was some burning material fallout at 5:24, with more at 5:35 (about 5 pieces fell at the same time). The pieces looked about 0.025 m by 0.025 m and appeared to be falling from the ceiling which was involved. At 6:15 there was a fair amount of material fallout. It seemed to be dripping down.

- FAA tape, test #30 (different view) - Burn-through at bottom corner edge of the bin occurred at 5:50.

- FAA tape, test #30 (different view) - Shortly after 6:15, there appeared to be a failure of the bin door as it sagged roughly 20° down on the right. The door fell off at 6:48 with no more sign of flame.

- FAA tape, test #30 (different view) - There was some soot flying around at the 6:48 mark.

8.4. Cargo Container

Cargo compartment fires were simulated by Blumke.[19] Measured parameters included ignition time, burn through time and physical damage to the cargo liner. Composition of combustible gases, temperature-time histories and heat flux. He reported that cargo fires were generally rare and successfully controlled and described the container volume, ventilation, loading, and instrumentation used.

Two tests were performed, the first maintaining the ventilation air flow after the fire and the second reducing the airflow through the compartment after smoke detection. Progression of the fire was described and some visual data, temperatures and gas emissions given.

It is however, difficult to assess behaviour of cargo fires since cargo materials vary so greatly.

Fire

SPECIFICATION:	Flames appear at about 60 seconds and progress toward air inlets. Growth or progress of the fire can vary according to what is burning.

- Blumke, 1977, test 1 - Ignition occurred at t=0. Flames were visible at 1:10 minutes. The fire progressed towards the air inlet. No pressure change was noted, so no flash fire occurred.

- Blumke, 1977, test 2 - Flames only occur at 3:27 minutes. Ventilation was reduced at 3:32 minutes. There wasn't a flash fire. Flames were observed at ventilation inlet after 5 minutes.

- Blumke, 1977 - There was a definite progress of the fire towards the inlets.

- Blake, 1983, Lockheed L-1011 Tristar - Flash fire occurred shortly after engine shut down. 23 minutes after engine shut down, a door was opened by the rescue team. 3 minutes after that the cabin was completely engulfed in flames. The fire, in effect, burned through a portion of the sidewall, ceiling liner and cabin flooring and began to spread through the cabin. The liner was made out of NOMEX.

- Blake, 1983 - Even for tightly sealed small compartments open flaming can last for a few minutes. If some ventilation is provided, the fire can burn continuously. For volumes ranging up to 3.1 m^3 and leakage up to 0.012 m^3/sec the flame is suppressed within 1 to 3 minutes. However, at 3.1 m^3 and 0.012 m^3/sec leakage, there are cases where the fire burns

intermittently. With a volume starting at 1.5 m^3 and leakage rates starting at 0.015 m^3/sec the fire burns continuously. It is stated that baggage fires in class D containers will probably not be fully extinguished such that letting air in at a later time will result in open flaming.

- Blake, 1983 - Growth of fire and intensity can vary depending on leakage rate, liner type, luggage type and the configuration of the fire load.

- Blake, 1983 - Heat flux on the ceiling liner was presented. Values peaked between 80,000 J/m^2 and 100,000 J/m^2.

- Blake, 1983, case history - BAC 1-11-500 had suitcase burst into flames while loading. Source was matches.

8.4.1 **Smoke**

SPECIFICATION:	Smoke obscures vision by about 60 seconds. This sometimes appears prior to response by automatic smoke detectors.

- Blumke, 1977, test 1 - One minute after ignition, smoke obscured visual observation. Centre smoke detector responded after 66 seconds, forward detector responded 2 seconds later and the aft detector signalled 76 seconds after ignition. Total obscuration according to smoke meter occurred 90 seconds after ignition.

- Blumke, 1977, test 2 - Airflow was reduced at smoke detection. Test was terminated after two hours. The first detector (UVIR) responded at 3:27 minutes

and the first smoke detector to respond was at 3:32. The last to respond was at 3:44 although one U.V. detector never responded.

- Blumke, 1977, test 2 - Obscuration took place after four minutes.

- Blumke, 1977 - Available were gas concentrations for the two test cases. Measured gases were oxygen, carbon dioxide, carbon monoxide, hydrocarbons and methane. These were of little relevance since the gases are ordinarily evacuated in a real aircraft.

- Blake, 1983, Lockheed L-1011 Tristar - At 1814:54, 6:54 minutes after takeoff, visual and aural warnings indicated presence of smoke in the AFT cargo compartment. 4:21 minutes were spent confirming the warnings, after which the crew decided to return to origin. The aircraft landed normally at 1836:24 and came to a stop after 2:40 minutes. Ventilation was stopped and valves were closed. Engines shut down only 3 minutes after coming to a stop, followed by a big puff of white and black smoke emitted from the aircraft belly just forward of the wings, as a result of a flash fire through the cabin.

- Blake, 1983 - The smoke detectors responses would not correspond to same levels of obscuration. The percent of light transmission over 0.25 m ranged between 78 and 94 percent for the ceiling smoke detector, and 90 and 94 percent for the flow through detector (although this detector's faster response is related to the proximity to the fire). Detection ranged between 210 and 536 seconds with

ceiling detector and 148 to 432 seconds with flow through detector. At some times, however, the detector would be destroyed by the fire. Furthermore, the smoke detector would often become saturated, indicating clear air when, in fact, there was dense smoke.

- Blake, 1983, case history - A 707 freighter crashed after heavy smoke was reported in the cockpit. A/C destroyed and crew members were killed. Crew could not function in continuously generated dense smoke. Source was exothermic chemical reaction.

- Blake, 1983, case history - A DC-9 was stopped on taxiway after smoke was reported. Source was a burning mail bag.

- Blake, 1983, case history - A 727 landed after reports of smoke in cabin and cockpit. Source was burning mail bag.

- Blake, 1983, case history - A G159 landed after smoke detector activated and smoke noted in cabin. Source was package against door light.

- Blake, 1983, case history - BAC 1-11-500 while loading had smoke billowing out of a suitcase. Source was matches.

- Blake, 1983, case history - BAC 1-11 had a suitcase emitting smoke while loading. Source was matches.

8.4.2 **Sound**

SPECIFICATION:	No sound above normal A/C operations.

8.4.3 **Temperature**

SPECIFICATION:	Stabilizes at about 300C, after about 5 minutes.

- Blumke, 1977 - The first test was completed after 13.5 minutes where the steel structure reached 320°C.

- Blumke, 1977, test 1 - In the first test, temperature stabilized at 5-6 minutes near the fire and at 9 minutes further on.

- Blumke, 1977 - After 2 hours into the second test, the fire was extinguished. The steel structure stabilized at 320°C after reaching a maximum of 335°C after the first hour.

- Blumke, 1977, test 2 - There was a temperature increase at flame detection followed by a rapid decrease and stabilization. Highest temperature of 590°C over the ignition source. Structural temperature reached maximum of 335°C. The second test had temperatures stabilizing or decreasing only after 60 minutes, although they were lower overall than in the first case.

- Blake, 1983 - Fires in large cargo compartments can readily reach damaging proportions even with immediate airflow shut off. A temperature vs. time curve was provided for different sizes of cargo containers. For 56 m^3 and up, temperatures reached a maximum 1000°C within 2.5 and 3.5 minutes (earlier for larger volumes). For 28 m^3 and 14 m^3, maximum temperatures were 470°C and 150°C reached

in 4 and 3 minutes respectively. By 12 minutes, all fires seem to level off around 150°C.

- Blake, 1983 - Curves were provided for temperature above and below the ceiling liner as a function of time. For the NOMEX liner, the peak below the liner was 900°C at 600 seconds. The peak above the liner occurred at the same time, reaching 670°C. By 600°C, temperature above and below stabilized at 290°C. Using a fibreglass liner, both temperatures peak after 240 seconds at 820°C below and 175°C above. Below the liner, temperature drops to 315°C by 500 seconds. Both temperatures drop to 150°C by 900 seconds.

- Blake, 1983 - The effects of ventilation were studied. The temperature below the ceiling grew hotter faster with increased ventilation. The type of liner also had an effect on the temperatures.

- Blake, 1983 - No matter what liner or ventilation was used, temperatures below the ceiling would eventually peak well above 540°C. NOMEX with ventilation would peak higher but much later than fibreglass with ventilation. However, the fibreglass curve drops off more rapidly. Cutting off ventilation delayed and reduced the temperature peaks. In this case, fibreglass would peak higher but later than NOMEX. Secondary peaks appeared before the main peak in all cases except for fibreglass with forced ventilation. Secondary peaks ranged between 1/3 and 2/3 of main peak.

- Blake, 1983 - Above the liner, temperature would stay below 320°C in all cases except for NOMEX with forced air which peaked at 650°C. The best

performance was for fibreglass with cut off ventilation where temperature above the ceiling liner climbed steadily to 94°C in 1000 seconds. Fibreglass with ventilation climbed to 350°C in 200 seconds and stabilized at that point.

- Blake, 1983 - Sidewall temperatures are generally slightly less than ceiling temperatures. Curves were given to compare sidewall temperatures with ceiling temperatures. The upper sidewall curve followed quite closely the ceiling temperature. The only difference was that the sidewall was about 38°C lower at the peak. The lower sidewall temperature followed as well except that it was 320°C lower than the ceiling at the peak.

- Blake, 1983 - A thermocouple was placed 5 feet from the originating fire and 6" below the ceiling. Tables were given for times to reach given temperatures. 65°C was reached within 10 to 960 seconds. 94°C is reached between 12 and 870 seconds, although, in certain cases, it is not reached at all. 120°C is reached between 14 and 475 seconds (not reached at times).

8.4.4 **Smell**

SPECIFICATION:	Acrid smell.

- Blake, 1983, case history - BAC 1-11-500 while unloading presented a strong smell of burning. The suitcase then gave off billows of smoke and an acrid smell. Source was matches.

8.4.5. **Material**

SPECIFICATION:	Delamination, charing and burn through.

- Blumke, 1977 - By the end of the first test, holes burned through the ceiling liner at 2 places and the liner was extensively delaminated at other places.

- Blumke, 1977, test 1 - Examination showed two holes where the fire burned through the ceiling liner (near the inlet). No other burn through existed. Ceiling and sidewall were delaminated and baked free of resin.

- Blumke, 1977 - By the end of the second test, a split occurred in the ceiling liner. Some areas were delaminated.

- Blumke, 1977, test 2 - This second test yielded damage mostly around the airflow inlet. A split appeared on the ceiling although no burn through occurred. Both the ceiling and sidewall panels were delaminated and the fibreglass was baked free of resin.

- Blumke, 1977 - In both cases, the ceiling was subject to burn through, although the sidewall integrity was generally adequate.

- Blake, 1983 - A 700°C flame 0.15 m in diameter will penetrate a liner of $0.0762(10^{-2})$m within 43 seconds. A 820°C flame will do it in 36 seconds.

- Blake, 1983 - NOMEX liners were seen to burn through each time (up to 40 seconds after smoke detection).

- Blake, 1983, case history - On a 707, a passenger notified flight crew that floor was hot. Plane landed safely, AFT cargo compartment was opened and fire was extinguished. Fibreglass liners were charred but not burned through. Slight structural A/C damage. Source of ignition was stored chemicals.

8.4.6 **Other**

- Blumke, 1977, p. 5 - Article states that the diversity of the cargo content, packaging and load arrangement adds a very random effect. However, it is stated that these tests are probably worst case scenario, and an actual fire will never reach these levels of intensity.

- Blumke, 1977, p. 7 - states that, in aircraft design, precautions are taken to ensure that cargo fumes are kept out of occupied areas.

- Sarkos, 1990 - class D compartments are designed for fire containment by oxygen starvation while class C compartments are larger and have their own fire detection and suppression systems.

- Blake, 1983 - reported ignition sources are kitchen matches, contact with light bulbs and volatile liquids or chemicals.

8.5. **Ballasts**

8.5.1 **Fire**

SPECIFICATION:	Yellow flames appear late in the combustion sequence.

8.5.2 **Smoke**

SPECIFICATION:	White, smoke wisps, steadily growing to plumes over 0 to 3 minutes.

8.5.3 **Sound**

SPECIFICATION:	Snap and hiss.

8.5.4 **Temperature**

SPECIFICATION:	No sensible temperature effects over 0 to 3 minutes.

8.5.5 **Smell**

SPECIFICATION:	acrid smell associated with electrical insulation fires, coupled with foul smell from the ballast and resinous delamination.

8.5.6 **Material**

SPECIFICATION:	No observable changes.

8.6 Galley Area

8.6.1 In Oven

Data on oven fires was not forthcoming. Consequently the specifications below are based on the experience of the APS team and are subject to the need for additional verification.

Fire

SPECIFICATION:	None visible.

Smoke

SPECIFICATION:	Thin, smoke streamers.

Sound

SPECIFICATION:	Crackling and hissing.

Temperature

SPECIFICATION:	No unusual temperatures.

Smell

SPECIFICATION:	"Food burning" smell.

Material

SPECIFICATION:	Buckling and rippling of oven doors.

8.6.2 **Oven Area**

There is insufficient data to provide specifications. The consultants cannot provide an opinion at this time. However, characteristics should be similar to the lavatory paper based fires.

8.7. **Remarks**

The following is a data set covering general aspects of in-flight fires.

- Sarkos, 1990, p. 5 - Occupant survivability largely driven by cabin flashover. Before flashover, smoke and toxic gas levels were minimal and survival is clearly possible. After flashover, smoke and toxic gases as well as temperature increase make survival unlikely. Flashover "is caused by the heat release rate of burning interior materials."

- Air Canada tapes - If fuel does not cool below combustion temperature during extinguishment, re-flash can and will occur.

- Air Canada tapes - There will be an increase in smoke after extinguishment due to smouldering combustion.

- McCaffrey, 1988, p. 3 - states that "aircraft cabins are generally ventilated from top to bottom. Fresh air is forced in at the ceiling of the fuselage and exhausted near the floor. Fires create hot gases with buoyant forces which are in the opposite direction from that of the ventilation flow. The inability to analytically characterize the resulting large scale eddy mixing process is responsible for the uncertainty surrounding the fire question."

- McCaffrey, 1988, p. 34 - His studies conclude that the bulk of the fire produced energy is not exhausted through the normal floor ventilation. The hot gases accumulate close to the ceiling and are barely affected by the incoming cold stream. Only when the cabin fills up does the ventilation have any effect.

- NFPA, 1984, p. 32 - Composite structures do not present any unusual fire fighting problems from the standpoint of extinguishment, as stated in the Manual for Aircraft Rescue and Fire Fighting Operational Procedures (p.32).

- NFPA, 1984, p. 13 - The manual states that fires where heaters are concerned have their own extinguishing systems.

- Blake, 1983 - A smoke detector is effective on a smouldering fire. A thermocouple is faster on flaming fires. Fire detection is more crucial on flaming fires.

9. SIMULATION CONTROL SPECIFICATIONS

It is clear from the results of the investigations that a considerably improved in-flight fire fighting training simulator can be built with existing technology and materials. This section summarizes the specifications in simple terms and provides the consultants view of the design specifications of such a simulator.

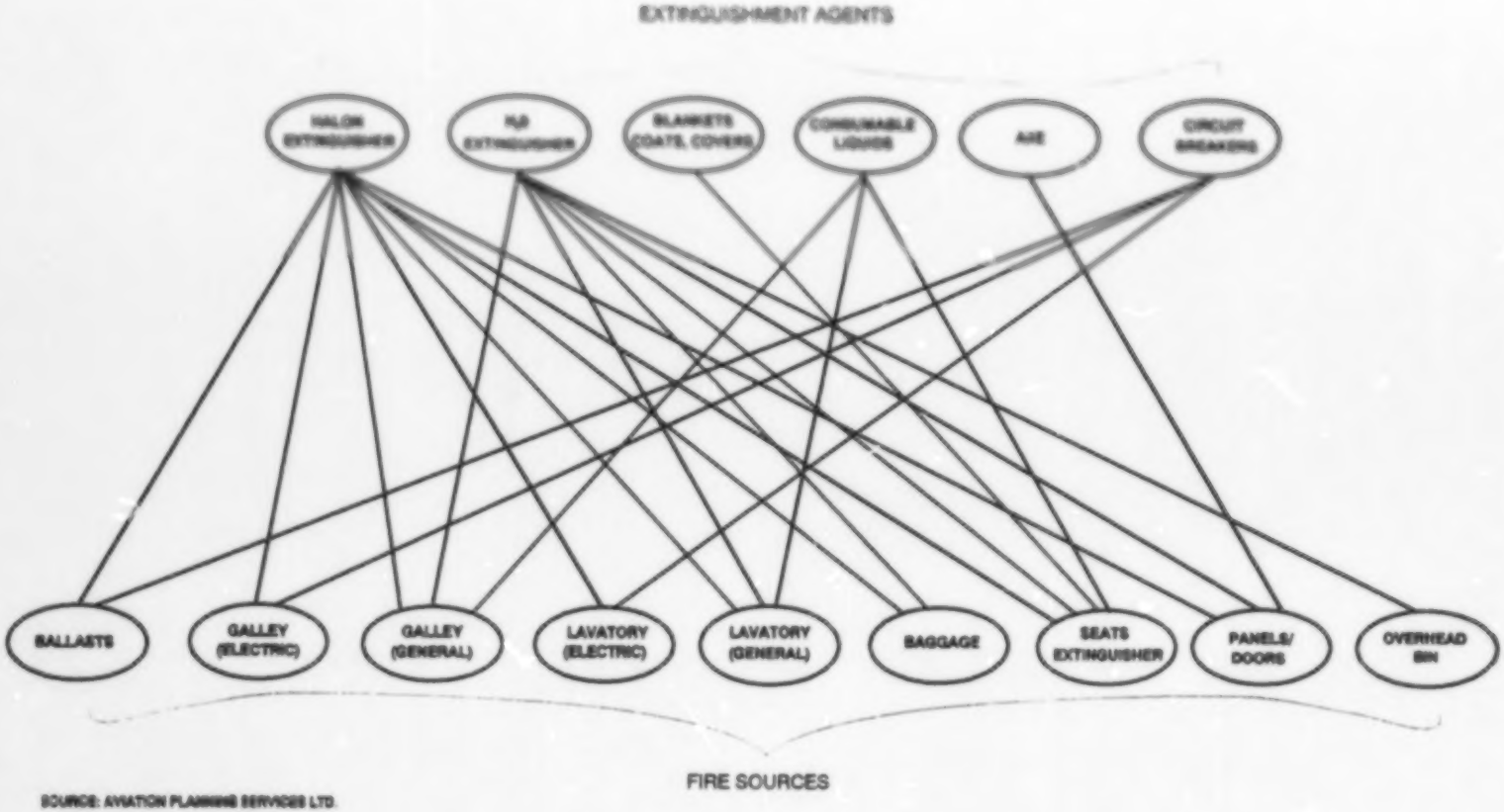
A simulator, such as the one specified at the conclusion of this study, would be computer controlled to allow realistic exercises to be selected by an instructor, with realistic responses to actions undertaken by trainees.

9.1 Fire Locations and Extinguishment Actions

The fire locations and the methods that can be used to fight them are shown schematically in Figure 9.1. For example, a fire in the lavatory would be fought with a Halon or water spray extinguisher, while a seat fire could be extinguished using either extinguisher, a blanket or other smothering device or a coffee from a pot.

The point of this diagram is to enumerate the elements which have to be simulated in order to provide a realistic training/testing device. Further, as has been previously stated, the locations within an aircraft cabin of each type of fire source should be variable or randomized from exercise to exercise. The fires in these locations could be initiated (simulated) by the trainer. The effects of the actions taken by the trainee should appropriately change the course of the simulation. For example, use of alcohol (simulated) to fight the fire (simulated), rather than tea, coffee or water, would cause flames to grow.

FIGURE 9.1
FIRE SOURCES AND EXTINGUISHMENT



SOURCE: AVIATION PLANNING SERVICES LTD.

9.2 Simulator Feedback Control Logic

The illustration, Figure 9.2, shows the flow diagram of the feedback control logic for the simulator. It shows the major man-machine components and their related interaction. For example, the instructor could select the aircraft region and the location of the site within that region to initiate the fire (cues representing a fire). The computer then controls actuators that simulate the specified fire and its consequences. That is,

a) fire appearance,
b) smoke/emissions,
c) sound,
d) temperature,
e) smell and
f) material effects would be created.

Then, the effects would be computer controlled to correspond to the actions taken by the trainee.

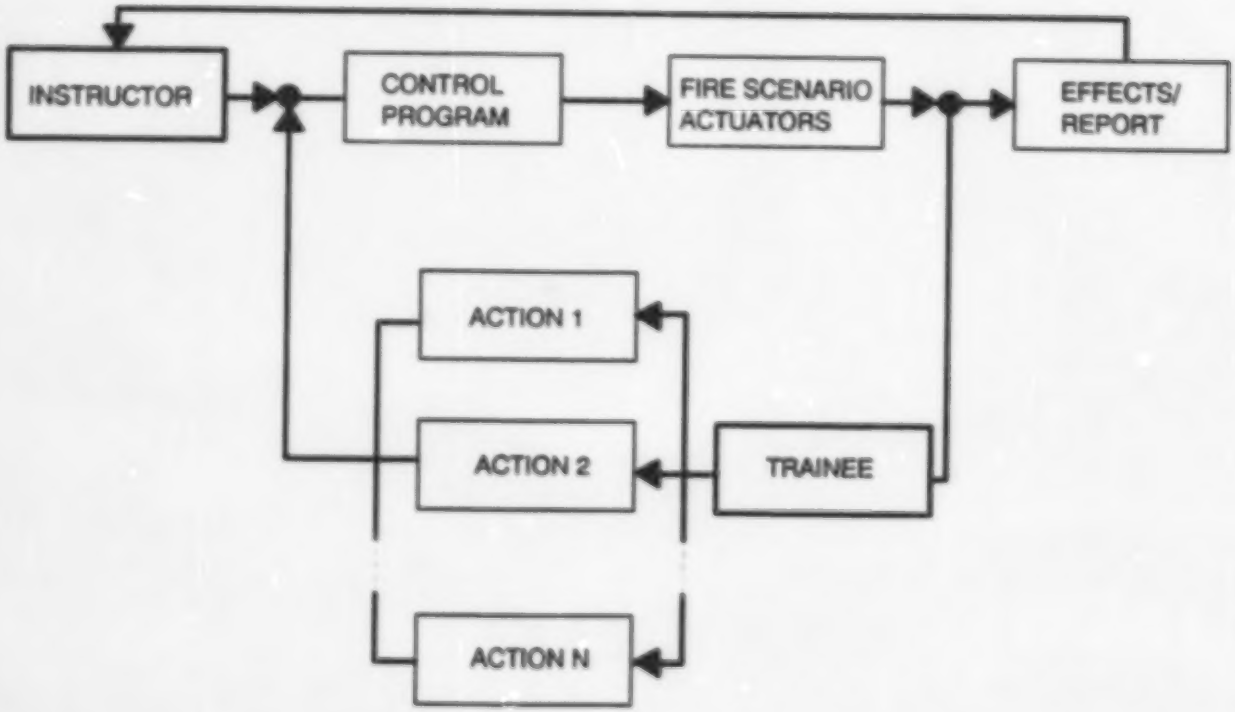
9.3 Fire History Simulation

The history of a fire without and with intervention is shown in Figure 9.3. The upper part shows a fire sequence scenario characteristic of the cabin, galley and lavatory areas, when no action is taken to fight the fire. The fire grows and then diminishes as smoke appears.

Initially there may be sounds that are relatively soft and smells which are pungent, but not strongly noticeable. As the fire grows smoke develops and the sound and smell grow.

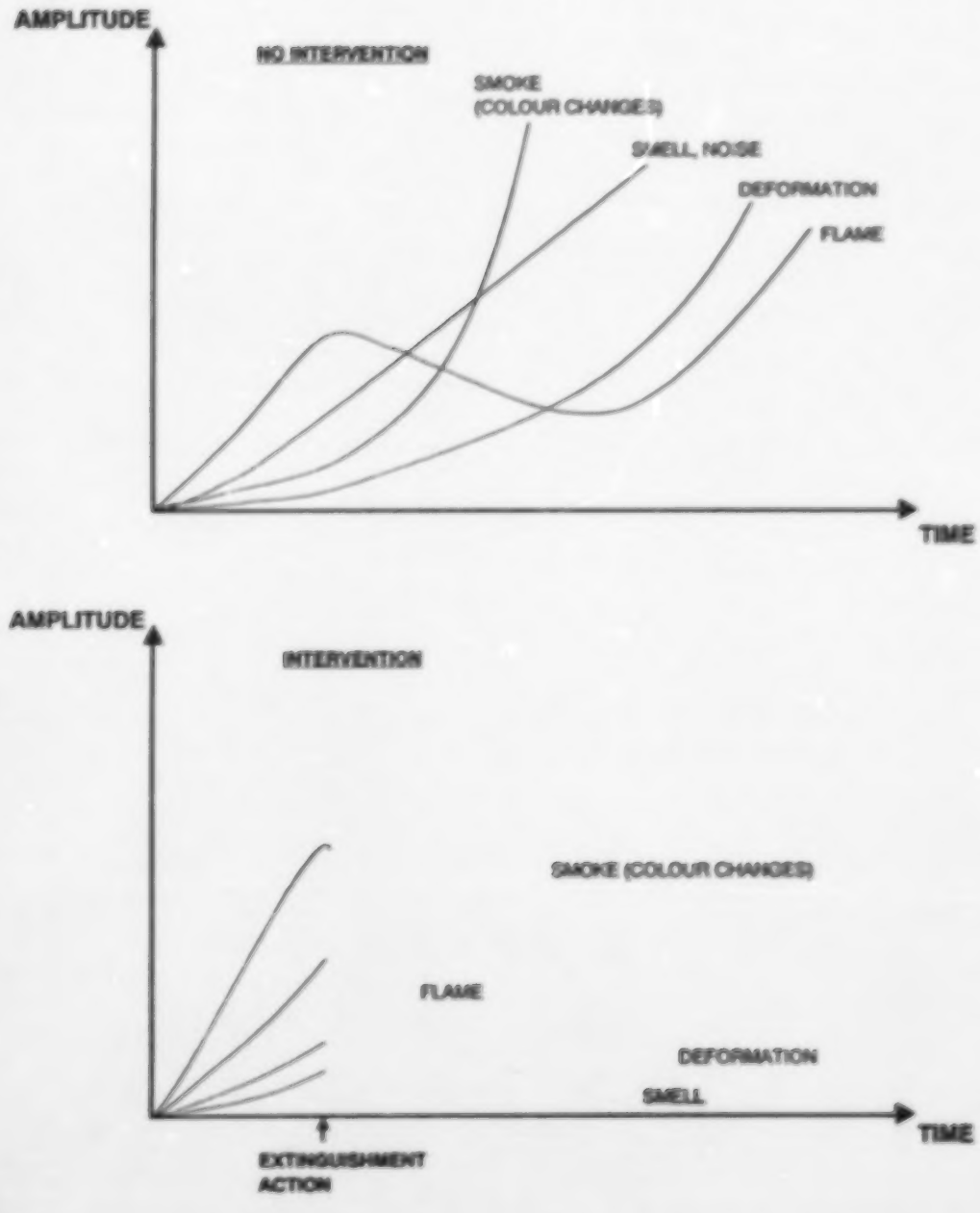
When the fire is extinguished, displayed in the lower graph of Figure 9.3, the fire disappears, but the level of

FIGURE 9 . 2
FLOW CHART OF SIMULATOR FUNCTION



SOURCE: AVIATION PLANNING SERVICES LTD.

FIGURE 9.3
FIRE CUES SEQUENCES



SOURCE: AVIATION PLANNING SERVICES LTD.

smoke emissions increases dramatically and the smell and sound increase beyond that for an unattended fire. The computer system should undertake to change the simulation as required, without instructor intervention.

10. COMPONENT SIMULATION SPECIFICATIONS

The entire simulator control should be such that the simulation is generated by the computer once the site and/or nature of the fire is determined. For example, if the instructor selects a paper bin fire simulation in the lavatory, the computer simulates all aspects of the fire and its history, and modifies the chronology to account for actions by the trainee.

The instructor should be able to initiate a training session involving fires in random locations or specified locations, interactive initiation of fires, or pre-programmed initiation of fires. Once initiated, the fire simulation should proceed unattended as observed in aircraft or inferred on the basis of experiments or expert opinion. Sensors in the simulator should respond to actions by the trainee and the computer should automatically invoke appropriate alterations for the simulation to correspond to the effect of the action of the trainee.

The following subsections provide specific summary statements related to the various components of the simulator.

10.1 Fire (Flames)

Flames can be simulated, for example, using holography, projection onto smoke or vapour and back screen projection. The interaction between fire and smoke is pointed out here. Normally, during the extinguishment process, smoke generation becomes profuse as the fire is extinguished. This may lead to the mistaken belief that the fire has not been successfully extinguished when it has in fact been put out.

10.2 Sound

Sounds can be replicated using recordings of fires in experimental trials. These sounds can be computer controlled, or computer driven to correspond to all other aspects of the simulation. In particular, the roar of steam and smoke generation can be expected to grow as the fire is extinguished. This is particularly the case for fires fought with water.

10.3 Smoke

Smoke should be generated outside the cabin so that the sound of the smoke generator is not heard above normal cabin noise. The smoke must be coloured over the range of observed colours, including white, yellow, blue and grey, Again, these are to be programmable, with computer-controlled feedback. In particular, if a smoking seat is covered by a blanket, the smoke emissions should be attenuated.

10.4 Temperature Effects

Two classes of temperature simulations can be employed. One involves the use of infra-red lamps to warm the skin and clothing of the trainee, while the other involves heating coils to warm sites in the simulator where fires are being modelled.

10.5 Smells

Commercial odour generators can be used for simulation of plastic materials based smells. These odours should not linger beyond the exercise duration.

10.6 Material Deformation

Deformation and discolouration may be simulated with mechanical or inflatable properties and with appropriate casting of shadows, respectively.

10.7 Physiological Effects

Suggestions for physiological effects are based on the consultants discussion with industry.

Generally, air line operators suggest that some nausea associated with a fire fighting simulation, when a smoke hood is not donned, can and perhaps should be tolerated. Nevertheless, the nausea and its effects should not be long-lasting. The consultants point out that nausea can be associated with smell, without any other physiological effect.

Next, heating effects should be warm enough to be felt, but not hot enough to burn.

Stress as a result of the simulation is to be expected.

In short, except for stress, the physiological effects should be limited to normal external sensations.

10.8 Hazards

There should be no hazards in the simulation, above what would be experienced in normal, in-flight operations.

No materials should be heated above their flash or ignition points. And, in particular, smoke should be generated without employing hazardous agents.

11. SIMULATOR STRUCTURE SPECIFICATIONS

Simulators of the cabin should be an acceptable representation of the aircraft with a minimum of 8 seat rows, for various wide-body and narrow-body aircraft types.

The simulator must be capable of handling (simulating) the effects of the following extinguishers: (1) water, (2) halon, (3) blankets and other dry smothering agents, and (4) other "ad hoc" liquids.

The use of extinguishers should be sensed and monitored by the computer for an interactive/adaptive simulation.

Extinguisher simulants should be non-toxic, rechargeable, and show no after-effects on the simulator. The extinguishers should simulate the weight, dimensions, appearance, controls and recoil effects of actual extinguishers. The extinguishers agents must have the same charge duration as actual extinguishers.

Between trials there are to be no residues, stains, smells or other histories remaining in the simulator.

The simulator should be constructed of low-cost replaceable panels, in particular for cases where axes are used as part of the fire-fighting simulations and no history is to be left.

The simulator is to be modular so that simulator components for only those aircraft regions of interest need be acquired. In particular, galleys or lavatories should be simulated as stand-alone units for carriers that do not have the resources to acquire the complete simulator.

12. CONCLUSION

The consultants have completed what can be accomplished with the currently available data base and existing technologies. Changes can be expected as the data become more complete.

Although there is not sufficient detail in the literature to define the simulations in each case, and existing experimental data are limited because of unrealistic boundary and initial conditions, the consultants believe that a simulator can be developed using the specifications identified in Sections 8 to 11 as well as the expertise of individuals who have experienced in-flight fires.

Additional details which may prove valuable include development of acceptable training scenarios for skill development and retention, and regular retraining schedules.

Next, combustion codes remain in early stages of development. Nevertheless, compared to full-scale trials, their use may provide a relatively inexpensive means for development of realistic audio/visual scenarios, and provide experience with "what if" possibilities.

Finally, we point out that toxic materials including carbon monoxide (CO), hydrogen cyanide (HCN), nitrogen dioxide NO_2, ammonia (NH_3), hydrogen chloride (HCl), carbon dioxide (CO_2), halogen acid gases, sulphur dioxide (SO_2), isocyanates, acrolein and others can exist.[20] Their simulation should be limited to smell, as physiological effects are not desirable.

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APPENDIX A
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